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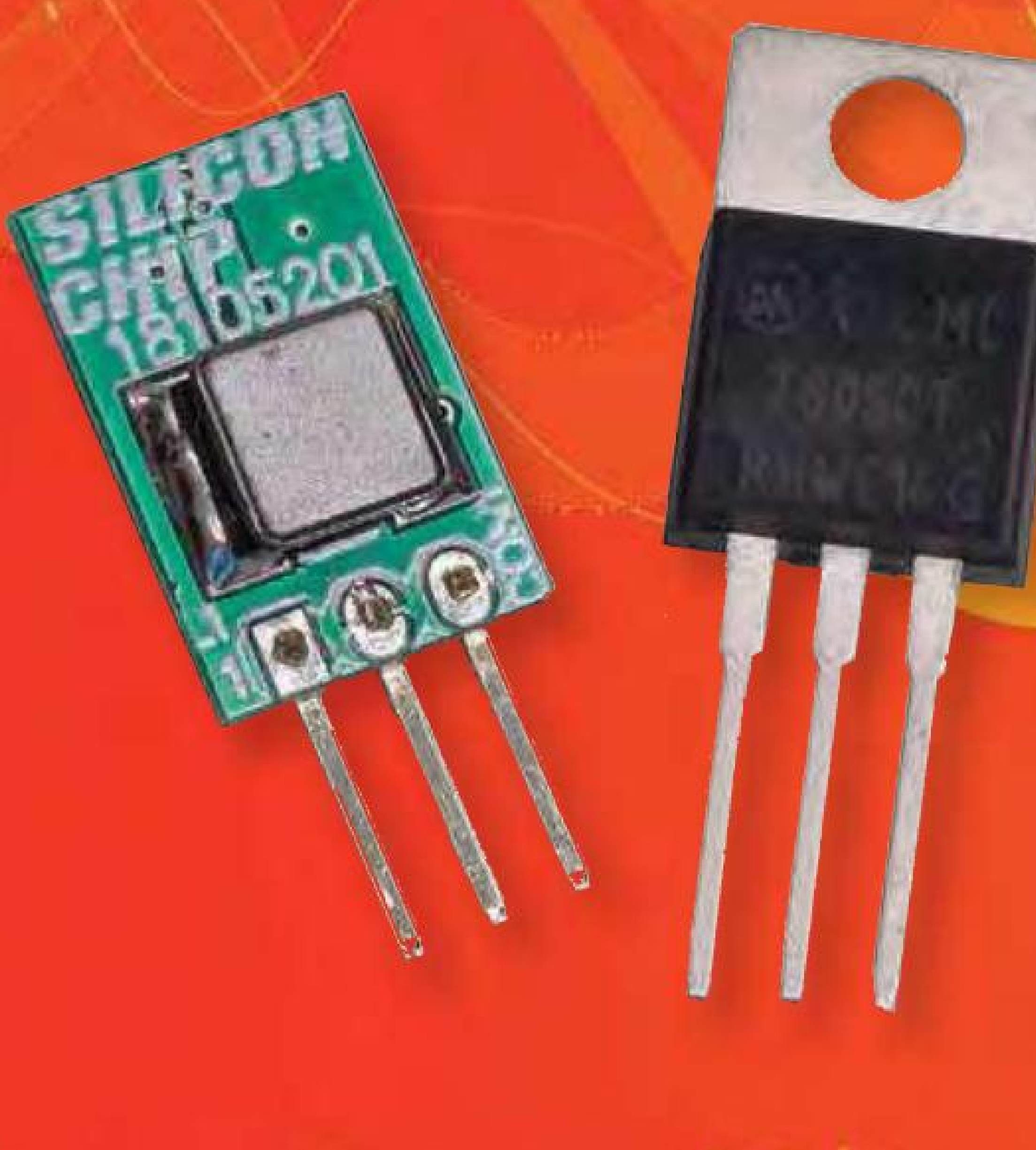
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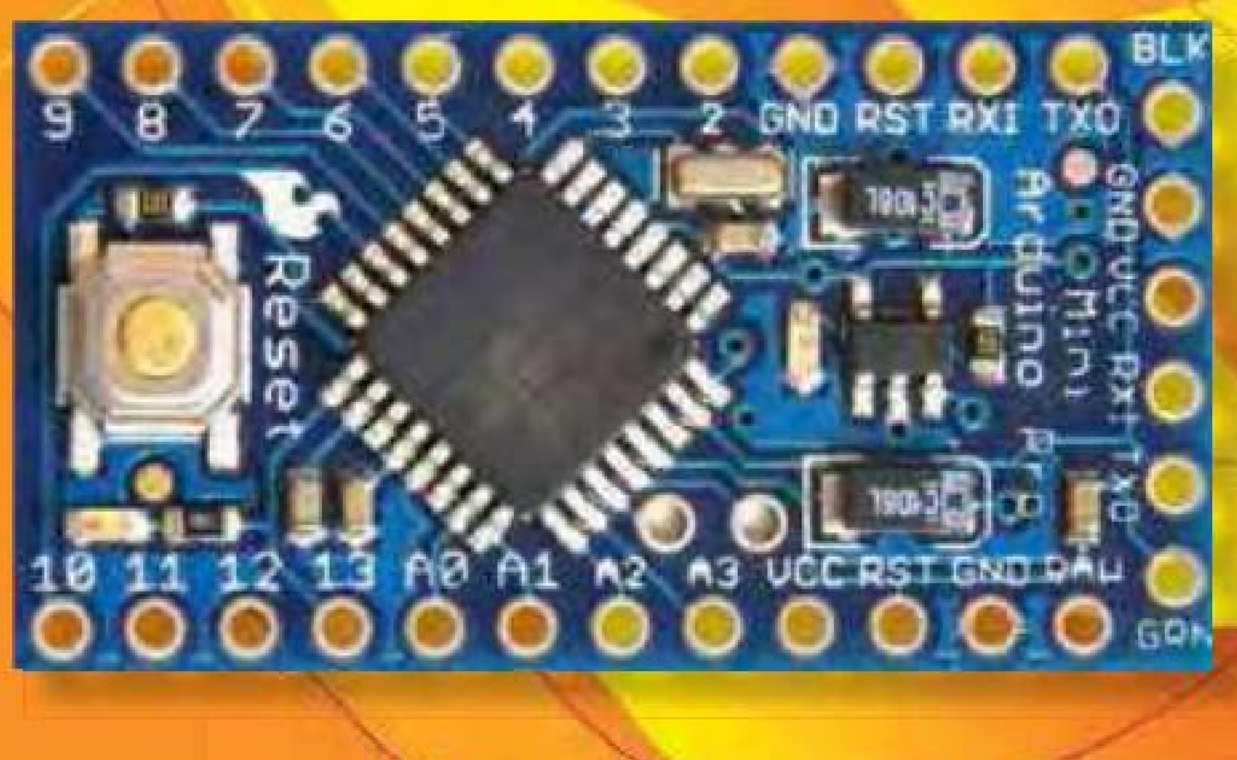
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GND VCC RXI TXO
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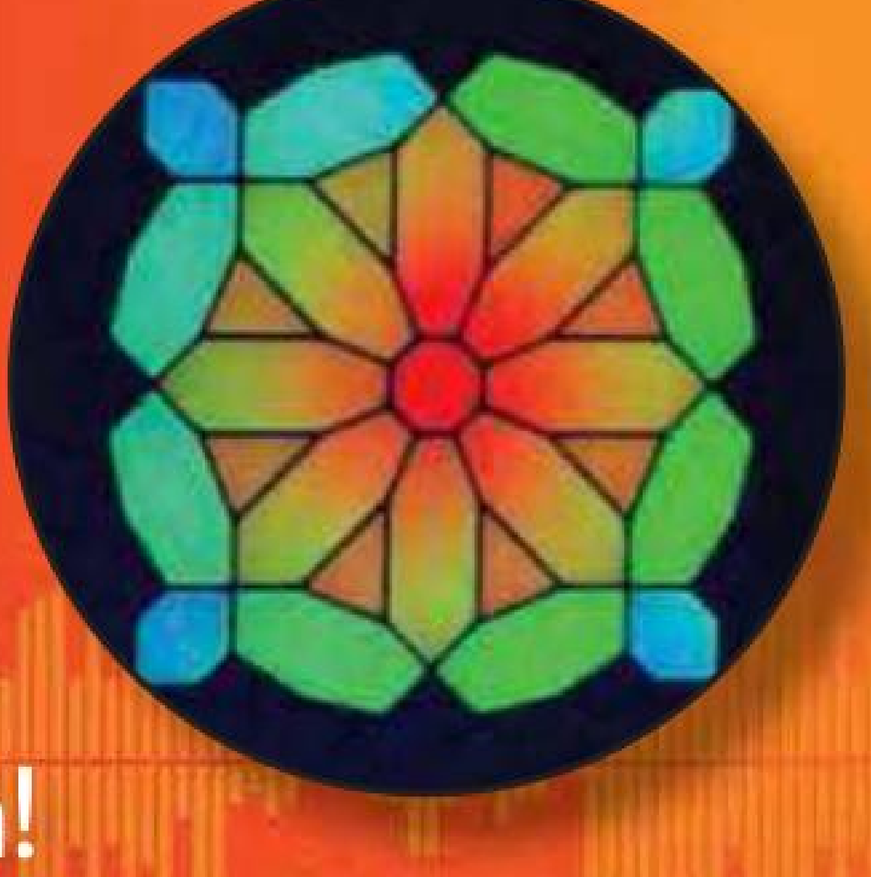

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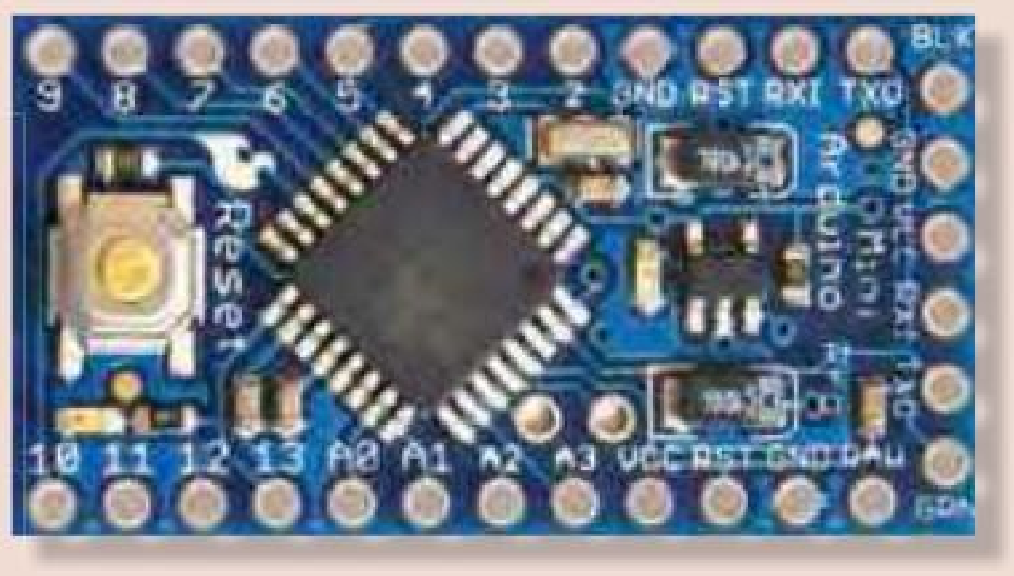

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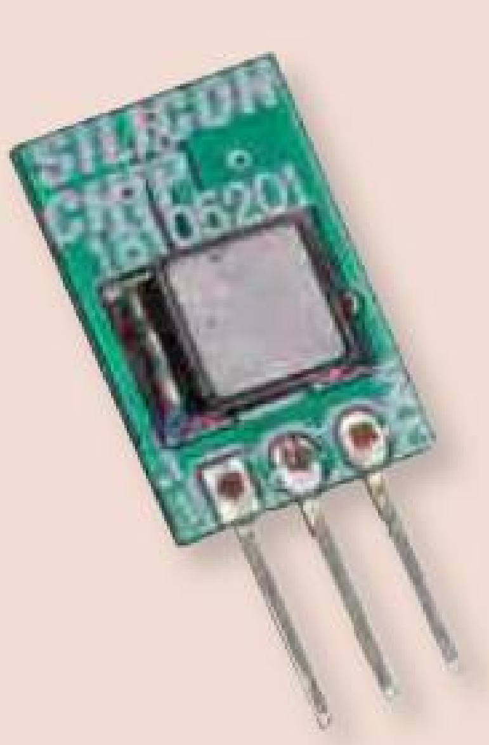

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The September 2021 issue of *Practical Electronics* will be published on Thursday, 5 August 2021 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

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The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

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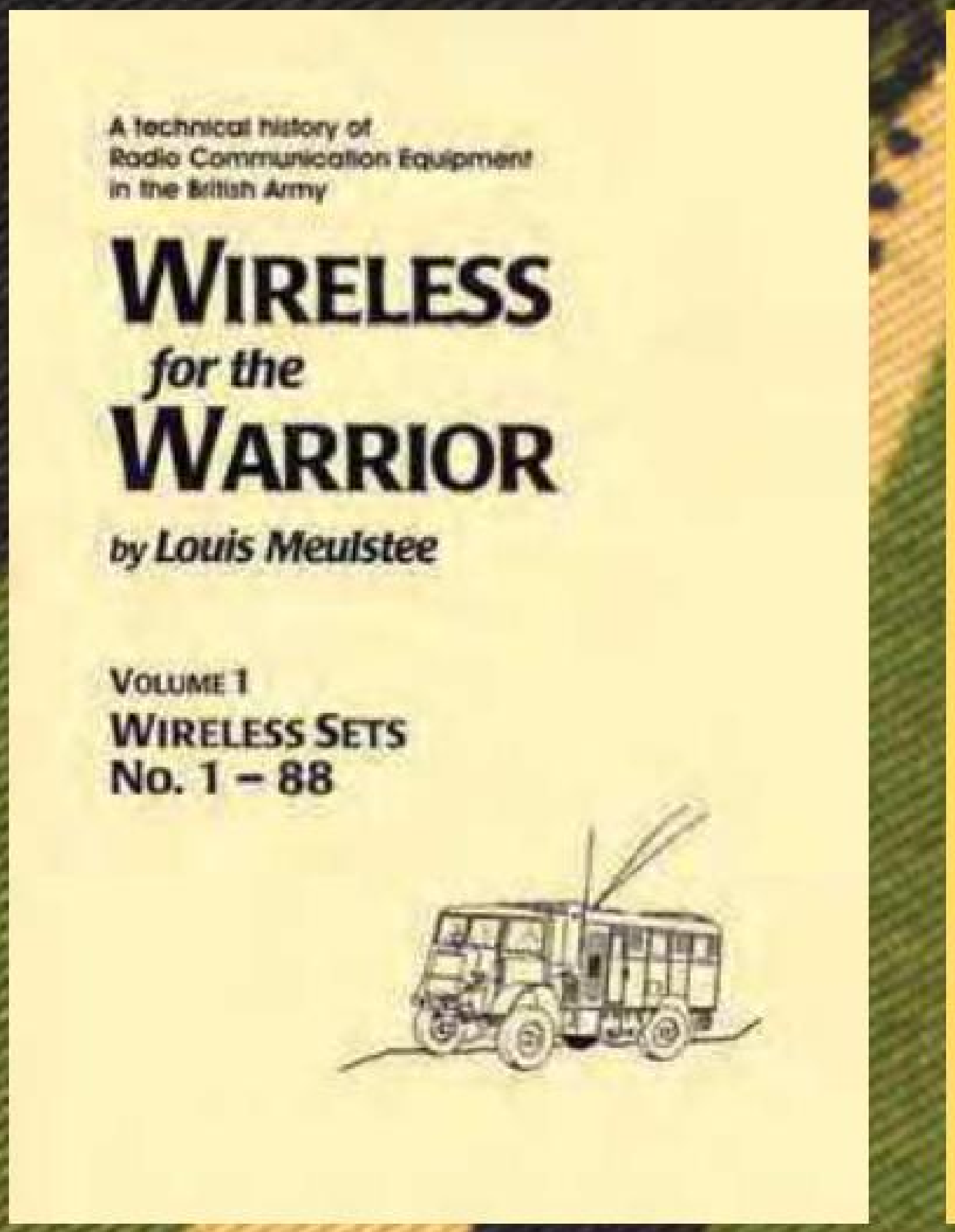
Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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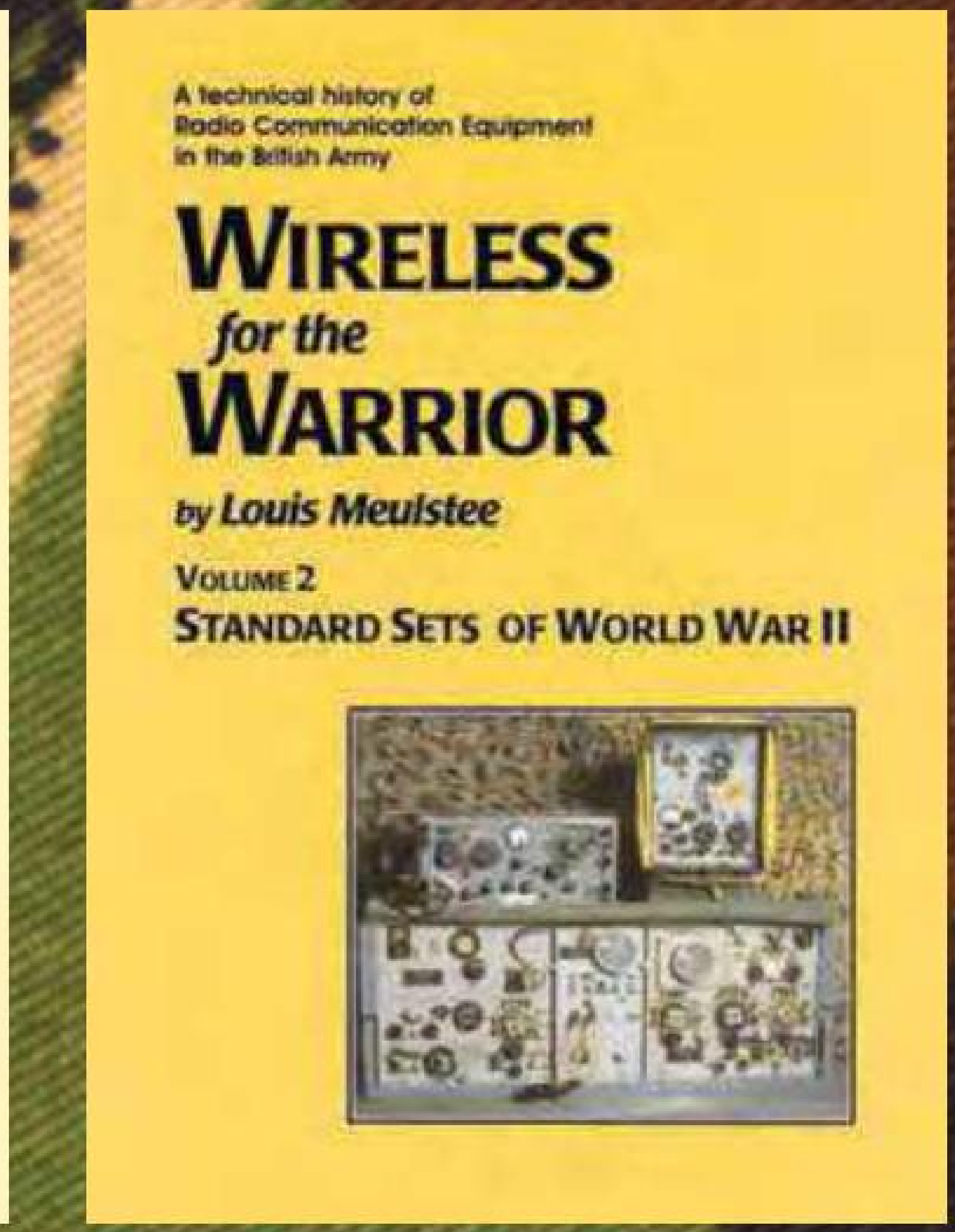

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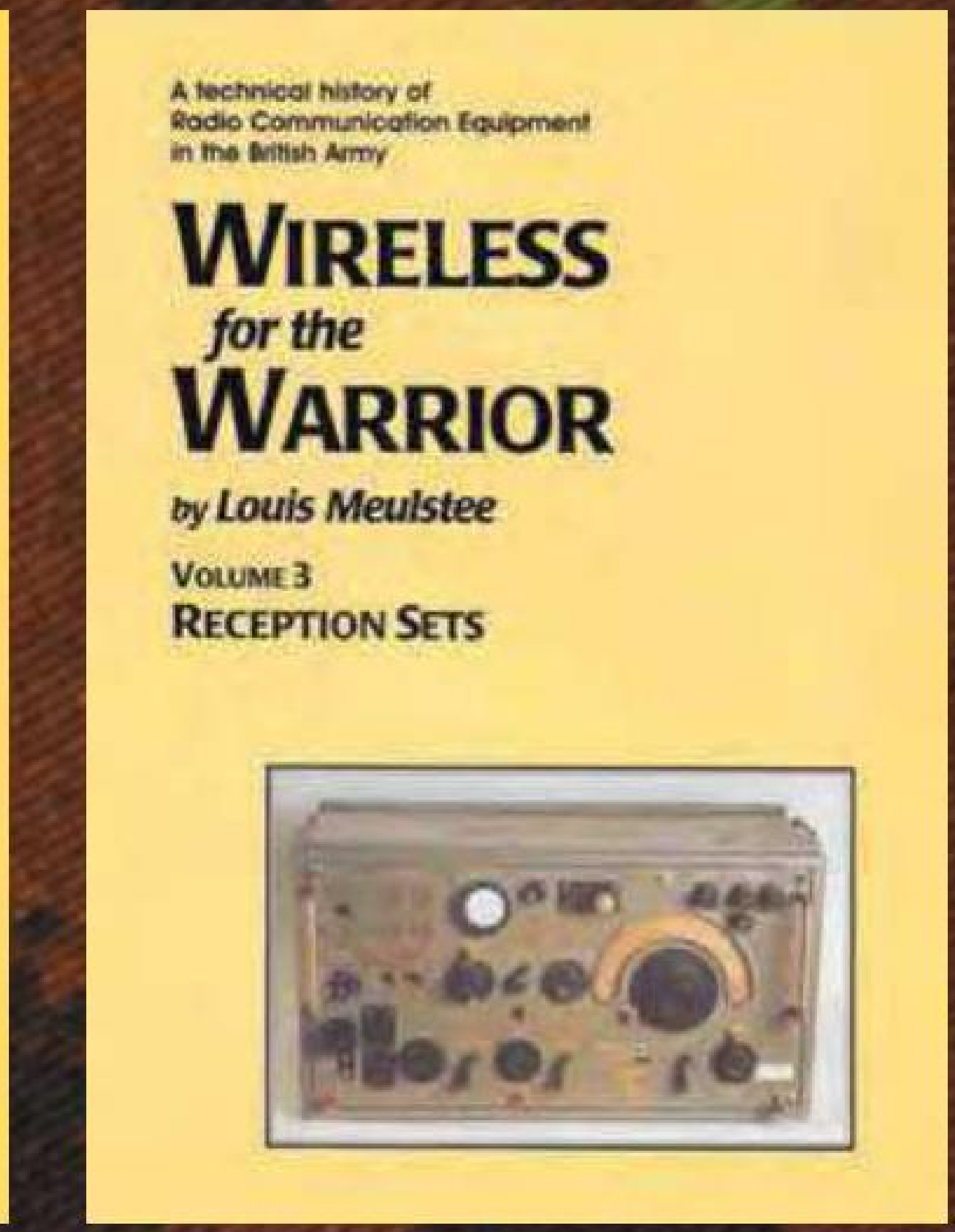

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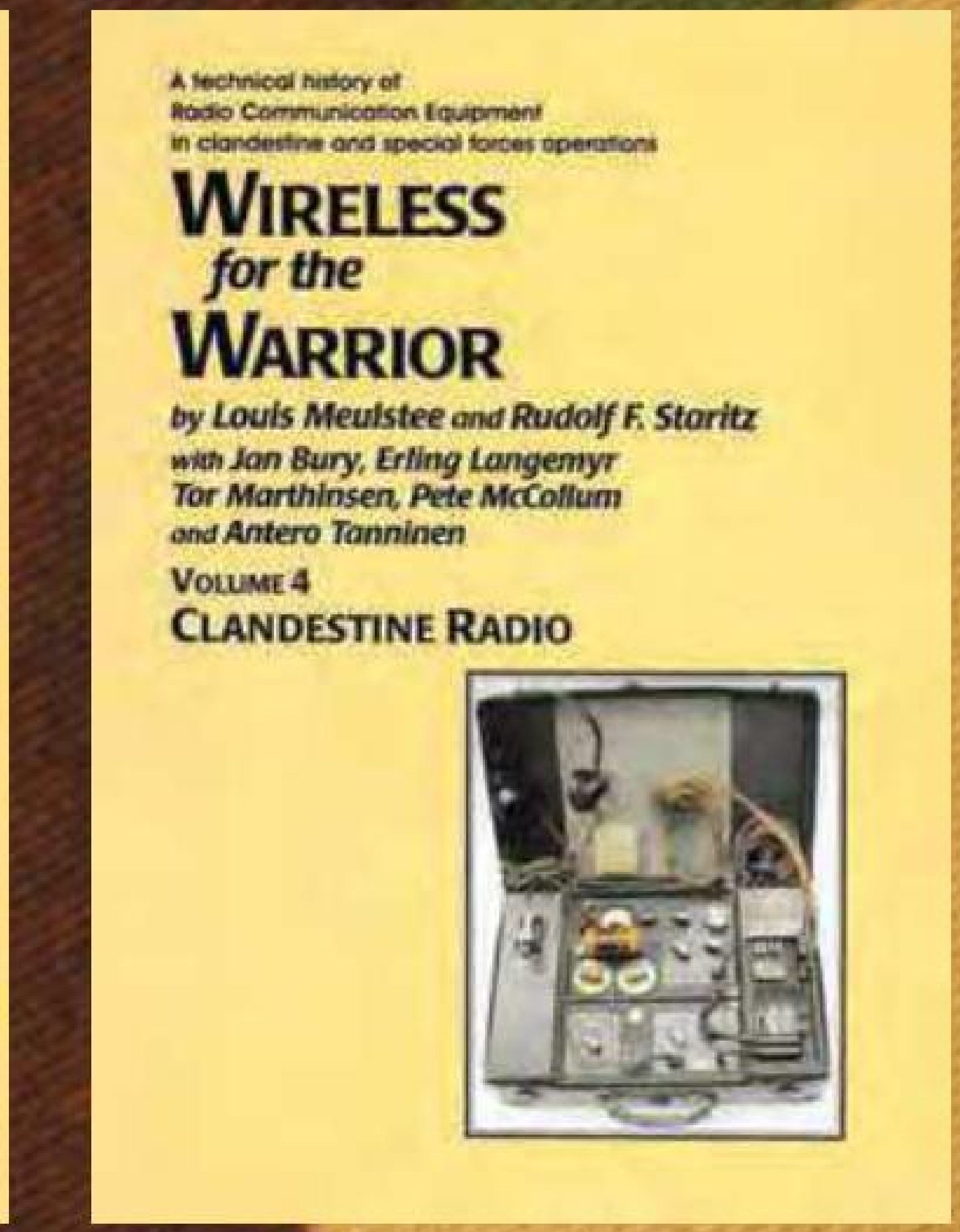

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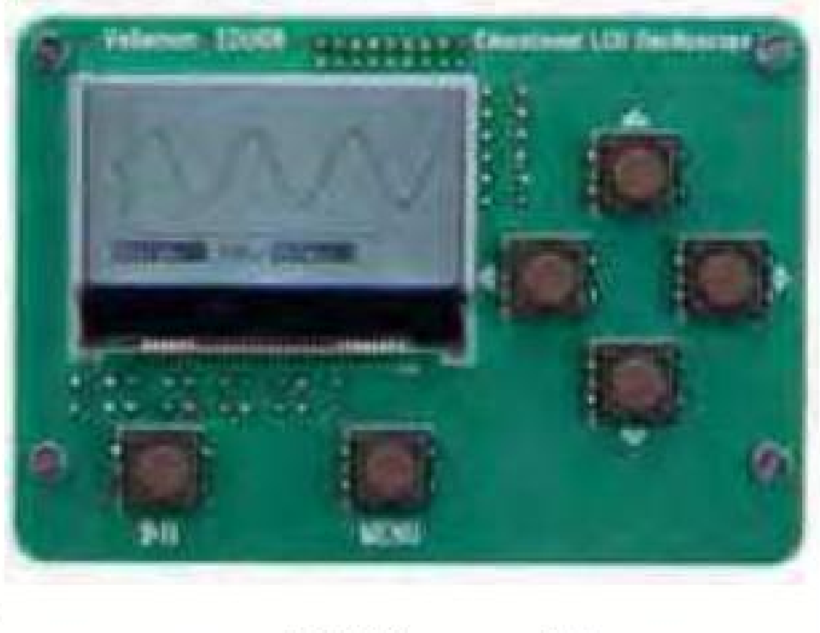

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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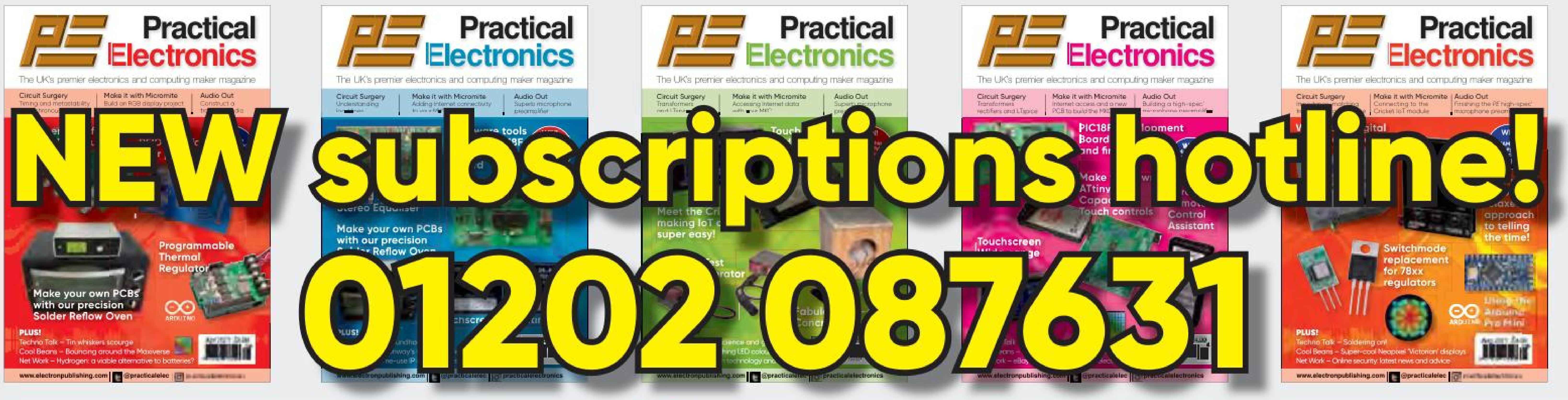

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Editorial

Projects, projects, projects…
We have a pleasingly eclectic collection of projects for you this month. First up is the *Ol' Timer*, an intriguing take on a digital clock that manages to tell the time without numbers or hands. A nice design bonus is the clever capacitive-touch technology built into its PCB in place of push buttons. We first covered this last month (see: *ATtiny816 Breakout and Development Board with Capacitive Touch*). It's a handy technology that could be transferred to many other projects. Why not give it a try?

Next, for all you RF fans, we have a *Low-cost, Wideband Digital RF Power Meter* that uses some cheap pre-built modules that when assembled produce an excellent piece of instrumentation – thoroughly recommended!

Is there any one of us who hasn't used at least one 78xx linear regulator? For decades, their simplicity and reliability have made them the go-to solution for quick and easy regulated power supply construction. They do have one major problem though – they can be inefficient. Now, though, that is a problem of the past thanks to the *Switchmode Replacement for 78xx Regulators*; a brilliant little design that enables you to build a drop-in replacement for 78xx regulators with a much more efficient switcher.

PCBs back in stock!
Recently, we've had a couple of minor problems with PCB deliveries that unfortunately turned into rather a long delay – so, apologies to everyone who's had to wait for July's boards. We've also stocked up on some older projects that had run low or even reduced to zero. So, if you've been disappointed recently when looking for a particular project's PCB then do try again, almost everything from the last five years is now in the shop.

One other shop reminder – don't forget that for all your *Audio Out* requirements Jake Rothman is now running the 'Audio Out Shop'. See page 5 for hard-to-find goodies at great prices.

EU VAT
Finally, a message for all our friends in the European Union. From 1 July, the EU will reduce the minimum value on imports that are liable for VAT from € 22 to € 0. We know why (no, it's nothing to do with Brexit!) – the EU has been losing billions in VAT through under-reported ecommerce transactions, mostly from China. Unfortunately, this may mean even single issues of non-EU magazines (ie, *PE*) become liable for VAT at their point of entry. In practice, it's hard to believe this is anyone's interest, but we will have to wait and see. The (unofficial) mood among EU post offices and shippers is that this would become an unbearable administrative burden for a truly tiny return, but the *official* position on magazines has not yet been declared. When we know more we will tell you.

Keep well everyone

Matt Pulzer
Publisher

The **Fox** *Report*

Barry Fox's technology column

Security issues

Online scams are getting more common and cleverer. Most involve trying to trick the recipient into revealing personal security information.

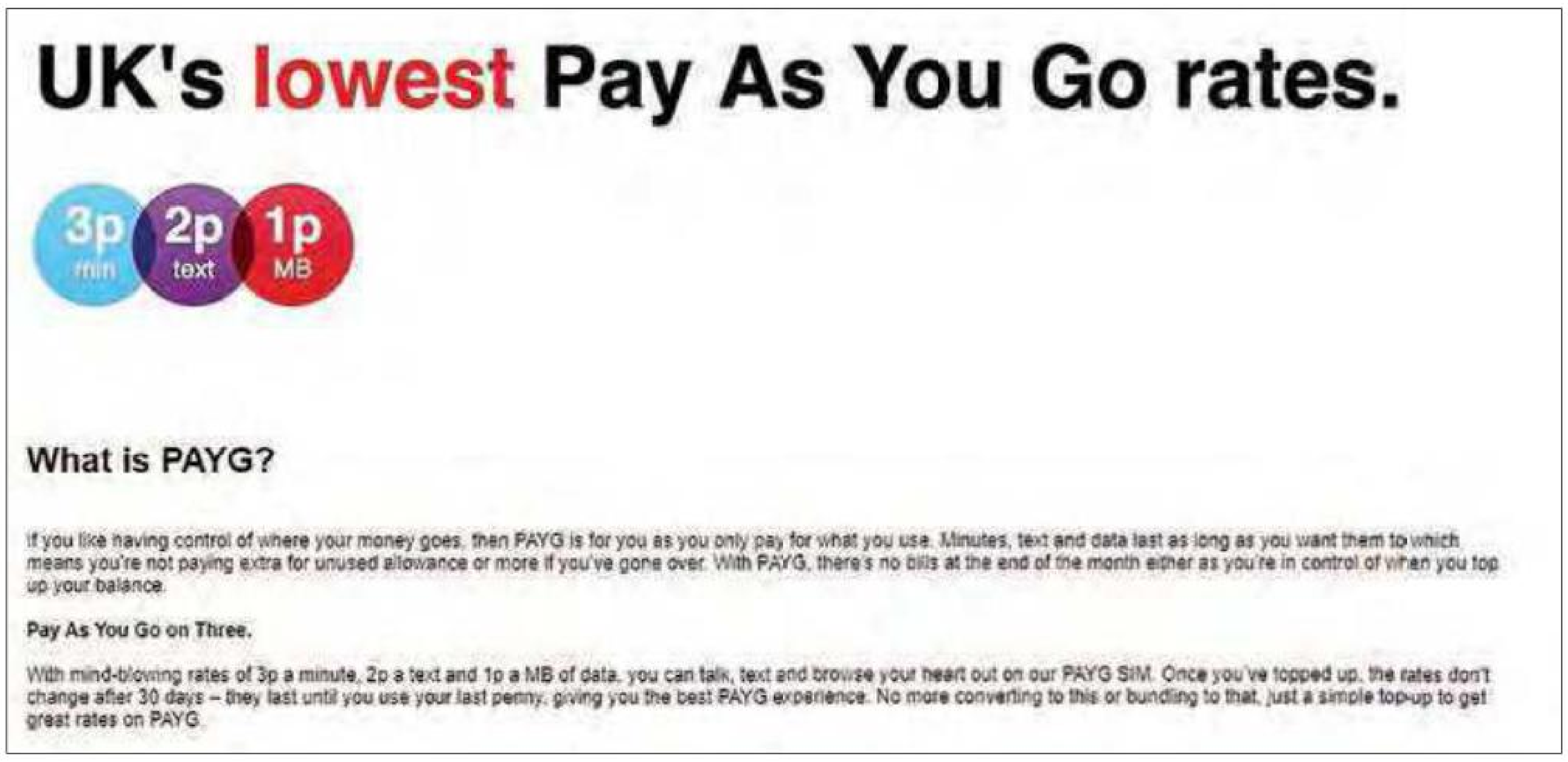
Date of Birth has little security value, because many people post it on social media, and it is there to read from any driving licence. The real value is of course in passwords and also memorable data like mother's maiden name, place of birth, first car and best school friend. Passwords can always be changed but memorable data can't; and it is frequently used for multiple accounts. So memorable data are gold dust.

We will never ask for…

Legitimate, security-conscious companies regularly warn that they will 'never ask for your password' and advise against revealing any personal account security data. So surely the customer relations department of a big-name British company would not be asking for exactly this information by email from a call centre clearly based abroad, before answering a broad question on company policy? But at least one is.

Hopeless customer support

Cellphone service provider *Three* requires customers to set up a personal account for purchase of credit. The account is attached to the user's cellphone number(s) and protected by password and memorable names.


UK's lowest Pay As You Go rates.

What is PAYG?

If you like having control of where your money goes, then PAYG is for you as you only pay for what you use. Minutes, text and data last as long as you want them to which means you're not paying extra for unused allowance or more if you've gone over. With PAYG, there's no bills at the end of the month either as you're in control of when you top up your balance.

Pay As You Go on Three.

With mind-blowing rates of 3p a minute, 2p a text and 1p a MB of data, you can talk, text and browse your heart out on our PAYG SIM. Once you've topped up, the rates don't change after 30 days – they last until you use your last penny, giving you the best PAYG experience. No more converting to this or bundling to that, just a simple top-up to get great rates on PAYG.

Three's 1p per MB PAYG price plan – still up on the web as of 21 June 2021.

I recently complained to Three about Three's action in increasing pricing for its 321 Pay As You Go service, with data charges increased fivefold from 1p per MB to 5p. Although the increases came into effect on 16 February 2021, I found out only when my credit expired five times faster than expected.

The company was still advertising the original pricing on its website in late June, long after I had alerted its customer relations department: **http://bit.ly/pe-aug21-three**

I asked Three's customer relations to address the broad issue of failure to warn well ahead of the increase and continuing to advertise the outdated rates. I also asked for compensation for purchased credit being used up at five-times the expected rate. But Three has repeatedly demanded disclosure of my password and secret memorable name security details before dealing with the matter.

Emails, largely in garbled English, from no less than eight different Three customer relations staff who do not seem to be referring to previous emails sent by other staff, repeat the same demand in different ways:

Hello Barry,
Thanks for getting in touch about your query.

We would need below detail so that I can look into this query, please reply to us with your:

- *Password (Memorable name or Memorable place)*

Thanks

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I have repeatedly tried but failed to get Three to understand that this is a serious security issue, writing:

*As you are my service provider you have full access to the accounts under my name Barry Fox for my Three numbers 07472**** and 07477****, so it is highly suspicious that you ask for my password, memorable place and name.*

Please now give me a full reply to my complaint.

What I get back is more of the same (also in dreadful English):

Thanks for getting in touch with us.

So that I can look into this query, please reply to us with your:

- *Password that you have Set on the Account as memorable place and memorable name.*

As you can verify your account with the password only, For security of your account. So that we can help you get a better outcome on the account. Three will do its best to help you with a resolution.

In other emails, Three says it has tried unsuccessfully to phone me, but without success, which is hardly surprising because it has been calling the number which is dead because credit has expired. In any case, I do not wish to discuss the issue by phone because I then have no written record of demands that compromise security.

It is also impossible for me to log into my Three account online and 'chat' in writing because this involves Three sending an account unlock code to the phone which is dead.

As the old saw says, you could not make it up.

Ofcom, ICO and ASA

I put the issue to Ofcom, the body which licences UK telecoms providers such as Three, and Ofcom suggested I contact the ICO (Information Commissioner's Office). This is, 'the UK's independent authority set up to uphold information rights in the public interest, promoting openness by public bodies and data privacy for individuals.'

I have asked the ICO to investigate Three's policy and will report back on how easy it is to get useful help from the ICO. For what it's worth – and being a glutton for punishment – I have also complained to the ASA (Advertising Standards Authority).

Try EE?

Meanwhile, it may help readers to know that a new(ish) service – 1pmobile – (which rides on the EE network) offers very similar rates to the 321 PAYG service that Three has withdrawn. I have been using 1pmobile for over a month now and not found any downside, yet.

The CD – Compact Disc audio

Inside an early British CD factory run by Nimbus in the Herefordshire countryside.

The basic idea of a small phonograph record read by a light beam that could play for more than an hour, with studio sound quality and never wear out, originated during the intensive development of home video discs by many companies during the mid-1970s. Eventually, almost all manufacturers accepted that the best video system was the laser optical videodisc – and this spun off the laser optical audio Compact Disc, the CD.

The first demonstration of a prototype CD was given by Philips at their headquarters in Eindhoven, Holland in the spring of 1979. But Philips could not go it alone. Support from the Japanese giants Sony and Panasonic was essential.

The fundamental principle of CD is simple – but devilishly hard to put into practice. A disc pressed from plastics has a spiral of very small pits and bumps in the surface, instead of a groove. The surface pattern is read by a finely focussed laser beam which reflects back into a light-sensitive cell. The light beam flickers and the light cell produces an on/off electric signal (digital 'words') which is decoded to make music.

Each pit or bump is only around one micron in size; by comparison, the groove of a vinyl LP is around 50 microns wide, which is the same width as an average human hair. Specks of dusts are huge by comparison. The discs have to be made in surgically clean air conditions. Philips liked to remind us that if a CD were enlarged to the size of the Roman Colosseum, the pits would be the size of match tips.

Philips was lucky that Akio Morita, the Western-thinking founder and then-boss of Sony, liked the idea of Compact Disc. Sony and Philips signed a deal in 1980 and Japanese and Dutch engineers worked together to improve the system.

Most importantly, they increased the Hi-Fi resolution from 14-bit words to 16 bits. They also agreed on a standard which would be the same all round the world, with none of the confusion caused by the different analogue TV systems then used (PAL for Europe, NTSC for the US and Japan and SECAM for Russia and France).

CD went on sale in Japan in October 1982, the next year in Europe and after that in the US.

Resistance to CD is as old as CD. In February 1983, British magazine *Hi-Fi News* published the thoughts of Ivor Tiefenbrun, founder of Linn (then famous for its turntables, later famous for CD players and now famous for digital streaming): 'CDs very, very substantially distort, degrade and compress the range of pitch relationships characteristic of virtually all music…if people listen to music reproduced on a compact disc player or on a digitally mastered disc… no real emotion whatsoever is experienced, other than irritation'.

Defence of CD is equally old. Soon after its launch, Oscar and Grammy-winning audio engineer and musician John Eargle came up with the never-bettered quote: 'If you have heard just one CD that sounds good to your ears, then that proves the system technology works; everything else you hear and don't like is a fault in the recording, the pressing or the reproduction – not the basic technology'.

More technology stories and images at:
https://tekkiepix.com/stories

Practical Electronics is delighted to be able to help promote Barry Fox's project to preserve the visual history of pre-Internet electronics.

Visit **www.tekkiepix.com** for fascinating stories and a chance to support this unique online collection.

Soldering on

Techno Talk

Mark Nelson

What's the oldest tool on your electronic workbench? In my case it's the soldering iron, a sturdy temperature-controlled example made by Oryx that I bought in the early 1970s. If you treat your iron with care, it may well outlive you! Let's delve a bit deeper.

I have several irons on my workbench, including five identical Oryx models, each equipped with a different size of tip. They are very robust, which must be why used ones turn up regularly on eBay. If I see them priced below £5, I snap them up without further ado. But I also have two Antex irons with tiny tips that I use for soldering surface-mount parts. I find this mixture of Antex and Oryx entirely satisfactory.

Most of the electronicists I know are equally partisan about the soldering irons they use. Some refuse to use any brand but Weller, whose irons seem to be almost indestructible and infinitely repairable. However, probably the majority of hobbyists are entirely satisfied with Antex, whose products are keenly priced and very reliable. Other British makes such as Oryx, Adamin and Litesold have fallen by the wayside during the last few decades, victims perhaps of the over-supply of stupidly cheap irons imported from the Far East, made for people who value price over robustness or personal safety.

Remarkably, the major names have a reassuringly long history. Across the Atlantic, Carl Weller patented the first hand-soldering tool to heat and cool rapidly in 1941. Four years later he founded the Weller Manufacturing Company near Philadelphia, Pennsylvania. Close behind him came the British firm Antex, which claims over 70 years of progress. I say 'British', but the company name in its early days was Anglo-Netherlands Technical Exchange Ltd and I am not sure exactly what the Dutch connection was. What's not in any doubt is that its products are manufactured to international quality standard ISO 9001:2015 and are fully compliant with all European directives on electrical safety and electromagnetic compatibility. Another stalwart of the soldering business is the firm called SR Brewster, alias Brewsters Ltd (on the web at: **www.soldering-shop.co.uk**). Currently, they retail Antex and other firms' products (they used to offer their own SRB brand irons, which looked uncannily like those made by Antex – both firms are based in Plymouth!). I confess to having a high regard for Brewsters, as they don't sell rubbish and crucially, they can still supply bits for certain obsolete types of Oryx and SRB soldering irons, which you would be hard pressed to find anywhere else.

How to...

Talking of soldering, I assume that every reader of this illustrious magazine knows how to solder, but amazingly we can often find new knowledge in books. As far as soldering goes, I reckon there are two 'bibles' that every electronicist will find worth reading. Reassuringly, neither of them will cost you an arm and a leg.

One of them is the *Basic Soldering Guide* by our own Alan Winstanley (he is too modest to plug his own book, so I'll do it for him!). Published in association with Antex Ltd, this paperback is an indispensable guide distilled from his 45 years of practical hands-on experience in electronics and will be an invaluable guide for anyone wanting to master the skills of electronics soldering for themselves. Its colour photography and crystal-clear text make it ideal for all readers – even better, it's available from the *PE* shop: **http://bit.ly/AW-solder**

The other title I commend equally to readers is *The Art of Soldering* by Richard Brewster, published by Bernard Babani Publishing at £3.99 and now in its eighth printing. It's available on Amazon and also from Brewsters Ltd.

Rot on

Now for a brief update on the DVD decay saga. A videophile reader writes in that the problem is not as simple as it first seemed. By accident, he checked a disc that he had already tested and declared unharmed. This second time it failed the test. Further investigation, playing through the disc from start to finish, showed the disc had failed completely. So, what does this mean?

'It's not just the case that a disc can rot on the shelf for years. Playing it once can finish it off! To date, the failure rate of Warner discs is about 4.6%. Tests on Sony and Fox factory discs thus far have been better. The worst are the 'made on demand' discs that are factory recorded onto blank DVD-R media (ie, not pressed). One that I bought for £14 in 2012 is now a coaster. It cuts out exactly halfway through. I've tried chilling in the fridge, using multiple drives, washing, but it's no use. What I still don't know is if UK products are affected. Time will tell, but Warner USA-derived DVDs made pre-2010 are all suspect,' he says.

I recommend the website **www.freevideoworkshop.com/fix-dvd-rot/** which offers plenty of insights but little comfort. If it's a commercial DVD with the dreaded rot, you can always go out and buy another one. But DVDs with family memories are irreplaceable. So, don't take any chances, it advises. Act before it's too late. Rip your DVDs to a digital format now. Once you've ripped your DVDs, you don't have to worry about DVD rot any longer. You then have a backup copy of your DVD which you can watch without a DVD player on your PC or other devices. To do this, you will need a PC and DVD ripping software (just search Google for 'free DVD ripper').

And finally

Have you heard about molecular memory? Eric Anslyn and his team at the University of Texas are researching the use of synthetic polymers of urethane-like plastics for information storage. This molecular approach offers a particularly appealing solution because it can retain information at far higher densities than leading silicon-based technologies. 'In theory, any kind of information can be encoded in polymers,' says Anslyn. 'In practical terms, we have seen books and pictures, among many other things, stored in molecules.' More at: **http://bit.ly/pe-aug21-mem**.

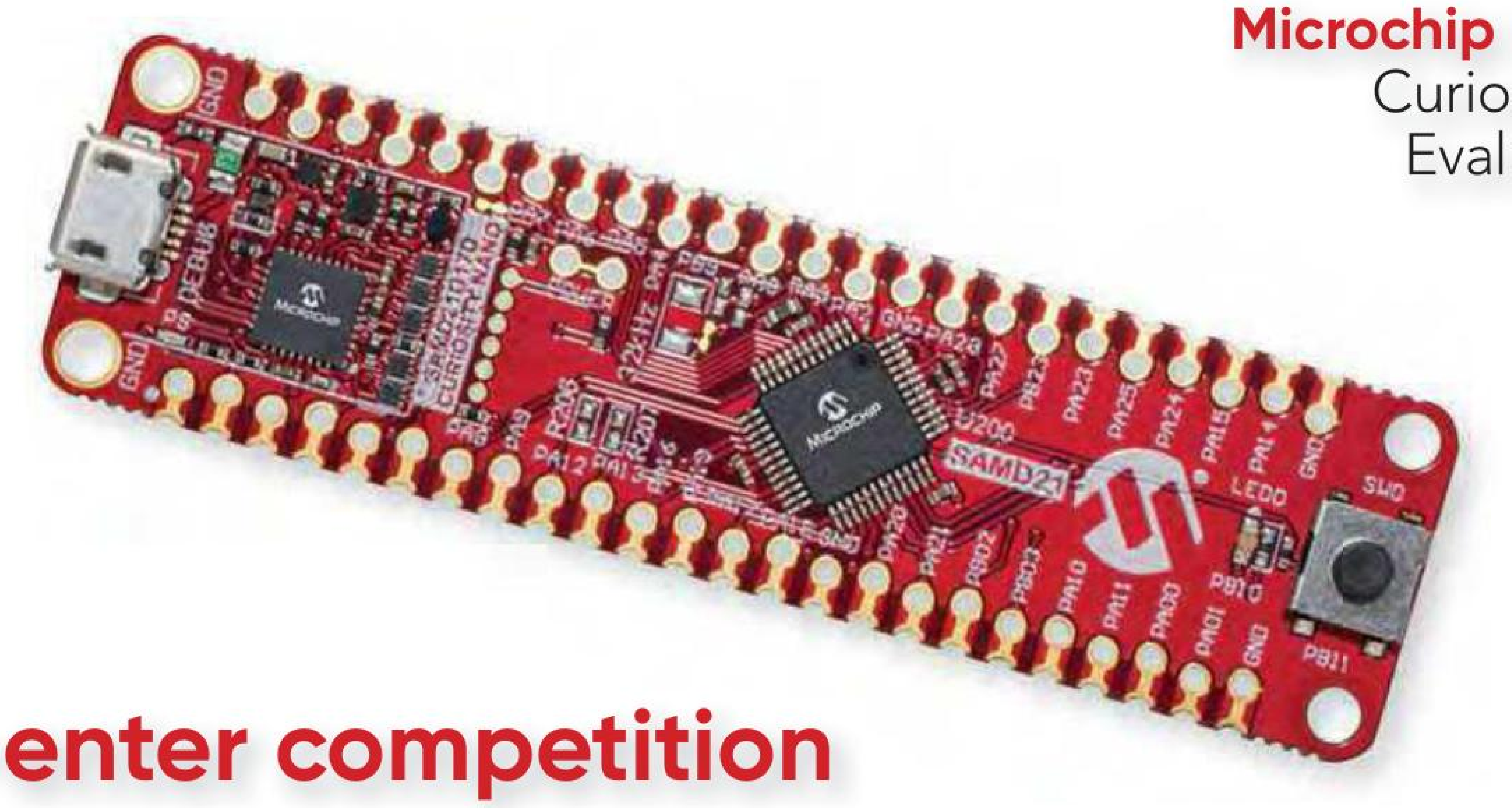
Win a Microchip SAM D21 Curiosity Nano Evaluation Kit

Practical Electronics is offering its readers the chance to win a Microchip SAM D21 Curiosity Nano Evaluation Kit (DM320119) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

The SAM D21 Curiosity Nano Evaluation Kit is a hardware platform to evaluate the SAMD21G17D microcontroller. This low-power, high-performance ARM Cortex-M0+ based Flash microcontroller is ideal for a wide range of home automation, consumer, metering and industrial applications. It features an ARM Cortex-M0+ CPU running at up to 48MHz, 128KB in-system self-programmable Flash, 16KB SRAM memory and six serial communication interfaces (SERCOM), each configurable to operate as either: 12-bit, 350ksps ADC with up to 14 channels or 256-channel capacitive touch and proximity sensing.

Worth $18.99 (approx £13.50) each

The SAM D21 Curiosity Nano Evaluation is supported by the MPLAB X Integrated Development Environment (IDE) and the MPLAB Harmony v3 software development framework. The evaluation kit provides easy access to the features of the SAM D21 MCU to integrate the device into a custom design. The evaluation kit is compatible with Curiosity Nano Base board (Part Number AC164162) which allows you to quickly scale and prototype your next innovative design using the SAMD21G17D MCU.



Microchip SAM D21 Curiosity Nano Evaluation Kit

Free-to-enter competition

How to enter

For your chance to win a Microchip SAM D21 Curiosity Nano Evaluation Kit or receive a 20%-off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-SAMD21.html

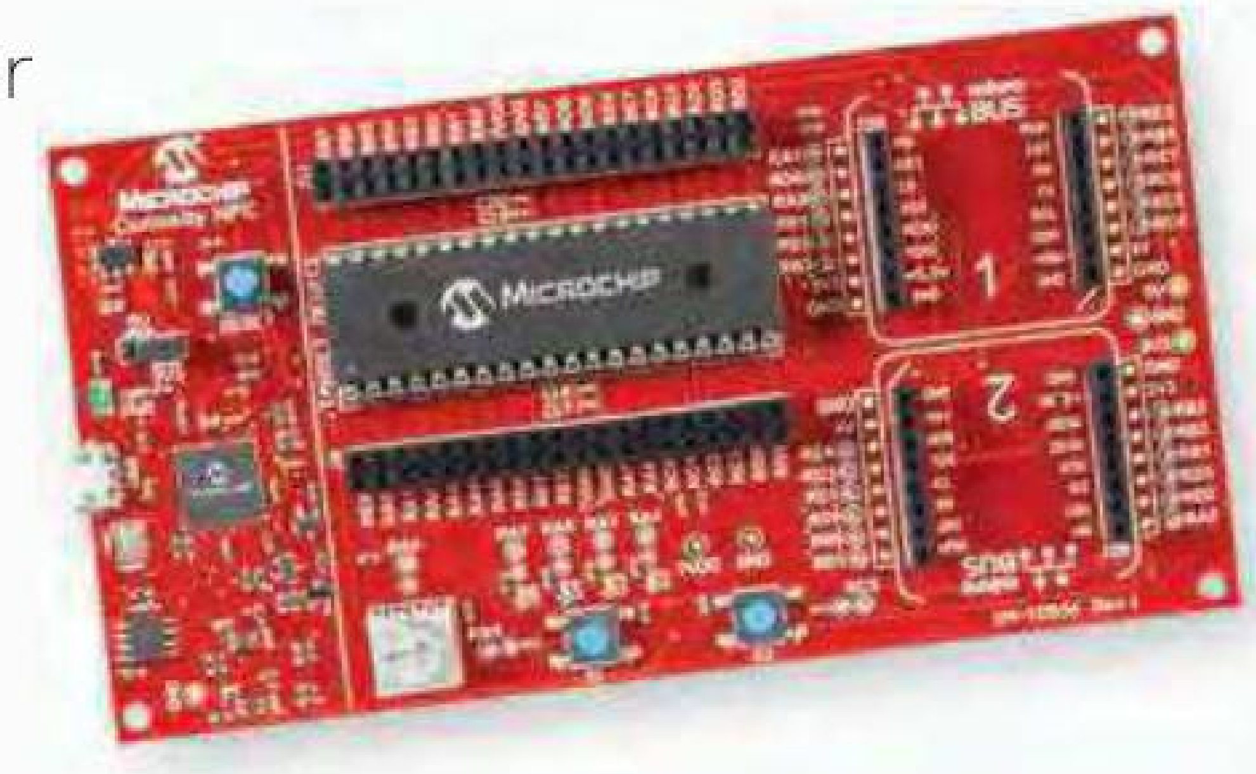
Closing date

The closing date for this offer is 31 July 2021.

April 2021 winners

Chris Hutton
Jan Svebakker

They won a Microchip Curiosity HPC Development Board



Net Work

Alan Winstanley

This month, Net Work looks at the never-ending problem of online security. From domestic fridges to critical national infrastructure, everything is online and we are all vulnerable.

Recently the author's ten-year-old deep freezer decided to throw a tantrum: although the digital display on the door panel showed '–18°C' as normal, breaking out my digital thermometer I found the temperature inside was actually +5°C. The whole interior had defrosted over the weekend but unfortunately the freezer had no low-temperature alarm. A lingering chemical smell alluded to a refrigerant leak, so the hunt was on for a new one from the usual online sources – preferably a European one, but I couldn't help noticing the Chinese Haier brand popping up everywhere I looked. Haier is a major manufacturer of white goods and electrical appliances, and claims to own 10% of the world market, having bought America's GE appliances business in 2016 and the Candy brand in 2019 (which includes the Hoover brand, popular in Europe).

Haier's Chinese-made appliances undoubtedly have a high 'showroom appeal' when viewed online; they are feature-laden and competitively priced. Some models feature Haier's 'Instaswitch' that converts it from a deep freezer to a refrigerator at the touch of a button. (I mused that my old South Korean freezer had done the same thing, all by itself.) More to the point, Haier Instaswitch freezers are Wi-Fi connected, which they claim alerts users of abnormal temperature rises caused by an open door or a power cut, for example. Owners can also control the temperature through their smartphone, Haier says. This appealing idea sounded like a deal-maker – at first, anyway.

Online reviews seemed generally favourable, although some users felt that the app wasn't very effective in practise. There's always a question-mark hanging over the lifespan of such apps, given that many smart TVs, radios and PVRs outlive the essential apps that help owners to control them. Apps can go obsolete all too soon, leaving dissatisfied owners high and dry. Personally, I wasn't willing to suck it and see and, after downloading the freezer's manual, I saw that changing the door hinge over was a complicated and fiddly two-man job.

China's Haier lays claims to 10% of the world market for white goods. 'Instaswitch' models (two shown) have Wi-Fi and can double as a fridge or freezer.

Keep it local

Being unable to check the build quality either, I eventually opted for a German brand, sourced from a local independent store instead. Working like my personal shopper or *Daigou* (see *Net Work*, February 2019), the store cheerfully compared the online specs. which saved me all the trouble, they suggested a suitable freezer, reversed the door in their workshop, delivered and installed it, and took away the old freezer and packaging all at a competitive price. Life shouldn't just be about price: if one factors in the many hours that one spends fruitlessly searching online before (fingers crossed) buying at arm's length, in my view any premium paid in 'buying local' is worth it just for the personal time freed up, and it helps keep the local economy ticking over too.

Surprisingly though, the German-designed unit still has some odd compromises: it seems that few freezers have digital displays showing the temperature inside in real time, and my new freezer hadn't one either. The LCD merely shows the desired set-point instead, although at least mine has a high temperature audible alarm built in. It also has a blinding LED light inside, and you have to open the door to check the digital display anyway, which is mounted above at head height! The force needed to pull the door open was enough to drag the freezer across the vinyl floor, something I cured by placing some discs of Scotchbrite material under the front feet, or bicycle puncture repair rubber could be used. (To help, the freezer was raised off the floor using a small inflatable 'air wedge pump' from eBay.) For a European appliance costing over twice the price of the Haier, these avoidable shortcomings were both ridiculous and frustrating. One can see why Chinese brands such as Haier are fast making ground in the marketplace, and online shopping puts them within easy reach of consumers. Haier appliances are available on Amazon and major UK appliance websites. Alternatively, South Korea's LG offers a wide range of Wi-Fi enabled appliances for the smart home, controlled by LG's ThinQ app.

Readers might enjoy some nostalgic glimpses of the electric appliances of yesteryear, particularly some quaint film presentations of American domestic appliances from a century ago. GE's electric cookers (stoves) and refrigerators were very advanced for their time when compared with British post-war equivalents. Enjoy the show, starting with life in the 'GE electrical home' in 1915 at: **https://youtu.be/gU2G9Frxyi4** (with awful music); 'A Design for Modern Living' (1935) at: **https://youtu.be/SVfZCKCzEWg** and

Westinghouse foretold the advent of the video doorbell in this 1950s film – but not cordless telephones! The object resembling a toaster is the screen. (Image: YouTube / History comes to life).

GE 'Pushbutton Magic' – demonstrating coloured pushswitch controls on a 1948 GE 'Stratoliner' oven (Image: YouTube / Museum of Innovation and Science)

'Pushbutton Magic' (1948) at: **https://youtu.be/sfiFFYpOB9Y**

In comparison, there is a 1930s museum piece of a British cooker at **https://tinyurl.com/yvhc6wcx** – while Westinghouse envisioned the 'Total Electric Home' of the future in a fascinating 1950s film, see: **https://youtu.be/jyrTgtPTz3M**

Incidentally, these links are ready-made for you to click on in my *Net Work* blog at: **www.electronpublishing.com/net-work-blog/**

Phishing without mercy

We've all had them – authentic-looking 'phishing' emails from fraudsters that try to lure you into clicking a link, perhaps leading to a bogus copy of an authentic website where your personal details or logins can be captured by criminals, who will then proceed to drain your bank account without mercy. Alternatively, the phony website might install malicious scripts on your computer, then connect to servers run by crooks which unleash ransomware on your system. A 'spear-phishing' email can be especially tricky to spot, as they look deceptively genuine; cyber criminals can steal names and email addresses for use in a convincing mailshot, supposedly coming from a recognised and trusted institution.

Savvy users soon recognise bogus spam mails that start with a generic 'Dear Recipient' or 'Attn. userx@gmail.com', but on a busy computer it's all too easy to click malicious links without thinking. A technique called 'Domain-based Message Authentication, Reporting & Conformance' (DMARC) is gradually being implemented. This authenticates emails and stops bogus ones from masquerading under a genuine domain or sub-domain name owned by, say, a bank or state institution.

At the time of writing, the author has been hit by waves of phony UK Government emails advising about eligibility for the fifth SEISS grant (funding for the self-employed during Covid-19). They are easily recognised and can be forwarded, preferably with the headers, to the UK Government's National Cyber Security Centre for attention. The NCSC says that they act on every report, and as of 31 May 2021, they had received more than 6,100,000 such reports, allowing them to remove more than 45,000 scams and take down 90,000 malicious URLs. In the UK, the email address to forward phishing emails (not spam) is: **report@phishing.gov.uk**

In both private and state-owned sectors, sophisticated social engineering methods can be used by impostors who sometimes spend months garnering the confidence of individuals before slipping an infected payload onto their network. Apart from visiting compromised websites, malicious file attachments such as a PDF or a .zip file containing executables, or innocent-looking Word or Excel files that contain harmful macros, can unleash devastating damage on networks and bring organisations crashing to a halt. Recent targets of ransomware attacks include the US firm Colonial Pipeline in May, which caused shortages in fuel supplies coinciding with spikes in demand as homeworkers started returning to the office. The attack was pinned on the DarkSide ransomware group, which reportedly 'apologised' afterwards, stating their only desire was to 'make money' and not inflict damage on society.

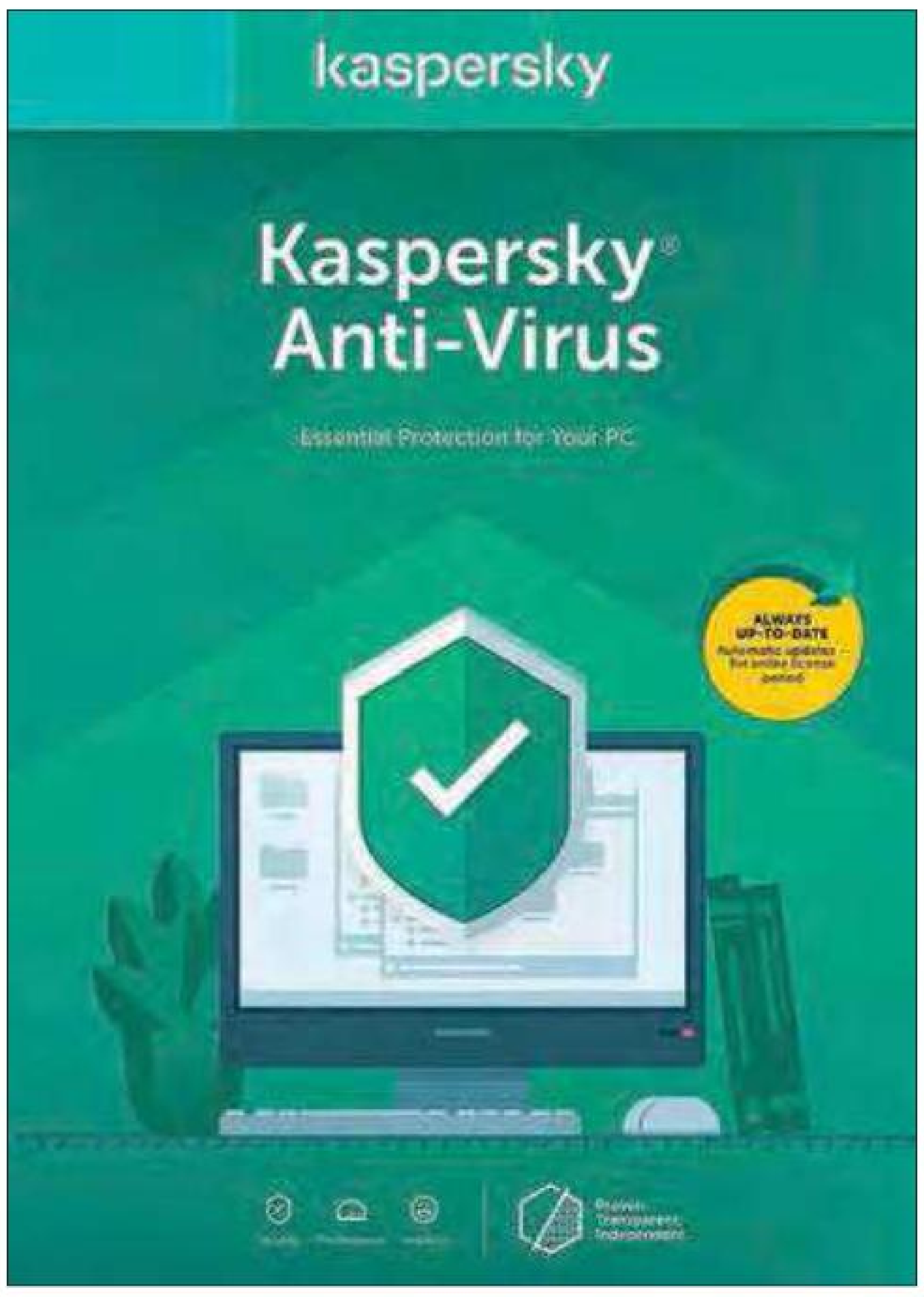
A plague on our houses

Ransomware is undoubtedly a 21st century scourge, and the threat is becoming so severe that this form of cybercrime is potentially being elevated to the status of a terrorist threat. Although official guidance is not to pay a ransom because that merely encourages more attacks, sometimes Bitcoins will change hands under the table in the hope of receiving a valid decryption tool from the criminals, although it can take many days to unlock and get systems online again. In the Colonial Pipeline case, it appears that some $4m in Bitcoin was paid due to the urgency of the fuel problems but, in what is probably a first in the cyber-security industry, most of this ransom was subsequently recovered by the FBI using some undocumented techniques. A phishing campaign from a 'help desk' then tried to trick Colonial workers into downloading more malware disguised as a 'system update to protect against ransomware'.

The world's largest meat protein producer, JBS, recently paid an $11m

SAFETY 24-7
COLONIAL PIPELINE CO

Colonial Pipeline – just one of the latest high-profile critical infrastructure victims of ransomware.



Kaspersky Anti-Virus – the author's online weapon of choice which works across multiple devices. There are plenty of alternatives, so do shop around.

ransom, it is reported, after suffering a cyberattack on its networks. With food production and fuel shortages now threatened by ransomware, the UK security services have held exercises to test the resilience of key infrastructure against such risks.

Ireland's HSE (Health Service Executive) was also hit by a major ransomware exploit attributed to the Conti criminal group. Serious disruption to healthcare was caused, but the villains reportedly had a change of heart and gave the HSE the file decryption tool for free, along with a menacing threat to publish private medical data if the HSE failed to further engage with them.

One technique that cybercriminals use to ramp up the pressure is to threaten to also release data onto the web, a method called 'double extortion' because both data encryption and data theft are involved. An emerging trend is 'triple extortion' where the cybercriminals also go gunning after the data subjects whose private information they have stolen, in the hope of raking in smaller ransoms from those whose personal information has been compromised.

Just a few weeks ago two University of Florida hospitals had to shut parts of their IT network after being struck by ransomware. Two schools in the county of Kent, England were also hit and had to close in June when pupil data was encrypted by hackers. It may be cheaper just to rebuild and restore systems from scratch. Japan's Fujifilm also suffered a major ransomware attack in June, but reportedly refused to pay a ransom and, commendably, restored its systems from backups within a week instead.

Vulnerabilities lurk everywhere, and the cyberthreat intelligence company Check Point Research (**https://research.checkpoint.com**) recently described possible weaknesses in certain staple Windows components that seldom receive any sort of make-over. Some could impact the security of systems running Microsoft Office software, for example. Hence, several Microsoft patches were released in May and June to fix the latest problem, but it also shows how our computers could be storing up headaches for the future as older Windows components that are taken for granted may contain as-yet undiscovered vulnerabilities.

Some versions of Windows 10 are now at end of life or heading that way, and will not receive any more updates or security patches. The website **https://endoflife.date/windows** gives a useful summary. Windows Update will gradually push the latest (21H1) onto systems to keep them going till December 2022. You can confirm your current Windows version via: Settings/System/About. In case users aren't aware, you can simply press the Windows key and then immediately type a keyword like 'version' or 'update' and Windows 10 will give you the necessary links to follow.

There's much talk of the next release of Windows: prior to the annual Microsoft Event that was held on 24 June, Microsoft uploaded a video of 'meditative sounds' based on old Windows system sounds at: **https://youtu.be/fM-r4Qm5ZWrI** – it's exactly *11*-minutes long, is that a clue about things to come?

Antivirus choices

An antivirus product is part of everyone's online armoury and will hopefully intercept and quarantine any infected files, or block access to a suspicious website, before any harm can be done. Many anti-virus packages have the odd irritating foible or two, and the author's choice of Kaspersky Anti-Virus is no exception, but it's competitively priced and seems to offer good all-round protection on multiple devices, including mobile platforms. Other anti-virus brands are popular with their loyal users, and some may bundle a VPN, password management, cloud storage or 'safe money' security to protect online banking transactions.

Try searching for 'Symantec' and you'll end up on Broadcom's website instead, which sells enterprise-level security software. Symantec's former consumer products are now sold under the familiar Norton brand (**www.norton.com**) owned by Norton Lifelock and, at the time of writing, Norton 360 Deluxe (5 devices) costs £19.99 in Year One and £84.99 a year thereafter. Watch out for costly automatic renewals that sleep-walk you into subscribing for another year if you don't cancel. In comparison, Kaspersky Internet Security (5 Devices) is discounted to just £18.14 for one year for a downloadable version, if bought via Amazon. The software licence is delivered flawlessly, and serial numbers are emailed and also stored by Amazon in the user's Games and Software library for future reference. Multi-device, multi-year licences are available. Alternatively, Avast Software still offers a free 'lite' version that's better than nothing and might be enough for occasional users (download it from: **www.avast.com**). Paid-for versions cost £39.99 (Year 1) and £79.99 per year thereafter (10 devices). Other reputable brands include McAfee, Panda Cloud Security, Eset and BitDefender. Many of these anti-virus programs can be bought and downloaded via Amazon, but there will undoubtedly be discount offers on the web so it's worth checking around.

In previous *Net Work* columns, I've suggested, and would repeat the advice here, that it is worth taking an 'air gapped' backup of valuable data onto an external hard disk or possibly a pocket SSD.

For storing lower volumes of data, plenty of cloud-based storage is available, including Microsoft OneDrive (5GB free), or Google Drive offers which 15GB free (Google account required). Apple's iCloud offers Windows users a program for syncing data hosted on a PC with their Apple devices. Phone security experts Certo Software recently published a blog about hackers targeting the iCloud in order to gain access to victims' phones. Certo tested a number of spyware products to see if it is still possible for hackers to gain access to the iCloud via these apps, as well as sharing advice on what you can do to protect yourself. iCloud users can read more at: **http://bit.ly/pe-aug21-cert**

Many of us still stash data away on optical disks as well, but perhaps re-read last month's *Techno Talk* column in which Mark Nelson described major problems that CDs and DVDs suffers during long-term storage: sadly, optical media isn't as reliable or robust as we'd all like it to be, so perhaps check out those archived disks sometime.

Last, on the subject of taking backups, Windows computer enthusiasts may like Macrium Reflect (free edition

Ealing, London now boasts the UK's fourth Amazon Fresh 'Just Walk Out' store.

available from **www.macrium.com**) or the interesting-looking Casper 11 from Future Systems Solutions. Macrium is a sophisticated, fast and powerful backup program that does a fine job of running backups on schedules over a network (onto a Synology NAS in my case), but it is quite a handful to configure at times. Casper 11 is designed mainly with disaster recovery in mind. It creates a full image copy of your system drive that can be used as an external boot disk, so you can carry on working as normal while a system is rebuilt in the background. Its maker claims that you can be back up and running immediately if disaster strikes.

This could be an ideal backup application for a pocket disk or USB 3.0 drive, although FSS warns that not all PCs support booting from USB-type devices. Casper 11 for Windows costs from $59.99 and both 32-bit and 64-bit versions are provided. I hope to test Casper myself in due course, also to test how well a boot disk might function on a different PC altogether. You can download a free trial from: **www.fssdev.com/products/casper/**

Other news

Recent *Net Work* columns have described the groundswell in electric vehicle production with numerous European and Chinese brands launching EVs, despite there being a paucity of public EV charging points. Owners are likely to face another menace as EVs become a more familiar sight: the theft of a car's charging cable itself. Stolen ones are quite valuable for scrap metal, but are also finding their way online as 'replacements'. No doubt cables will become an attractive nuisance for vandals or bored kids. I found some useful practical advice on how to safeguard your EV cable when it's in use on a YouTube video at: **https://youtu.be/mYHhqekij3E**

Ofcom's annual report, *Online Nation 2021*, cited some trends in UK internet usage in a 185-page analysis. In September 2020, UK internet users spent nearly four times as much time on smartphones (averaging 2 hours 19 minutes a day) than they did on computers (37 minutes). Youngsters aged 7 to 16 spend almost four hours a day online, mostly for gaming or watching streaming video, while young people in the 7-17 age group named YouTube as their favourite. By the age of 11, some 59% of children were hooked on social media, even though the minimum age limit was 13, Ofcom says, and 95% of kids used it by the age of 15. Google and Facebook consumed some 40% of the entire traffic across the board, though younger users aim for Instagram, TikTok and Snapchat. The full report is online at: **http://bit.ly/pe-aug21-ofc**

Amazon Fresh has opened its fourth 'Just Walk Out' store in the UK. Located in Ealing, London, it uses a combination of advanced technologies to check what shoppers actually put in their basket, and simply charges the total to their account without them needing to go through a checkout.

The sale of halogen bulbs is finally being banned in Britain as part of the move towards using more fuel-efficient LED bulbs. If your favourite light fittings use dimmable halogen bulbs, for example, now is the time to consider stocking up if you don't want to scrap them just yet. The ban takes effect on 1 September. High-energy fluorescent tubes are in the firing line as well – from 2023.

Don't forget to check those ready-made *Net Work* links on our website, and, as always, remember that I can be reached by email: **alan@epemag.net**. See you next month!

The author can be reached at:
alan@epemag.net

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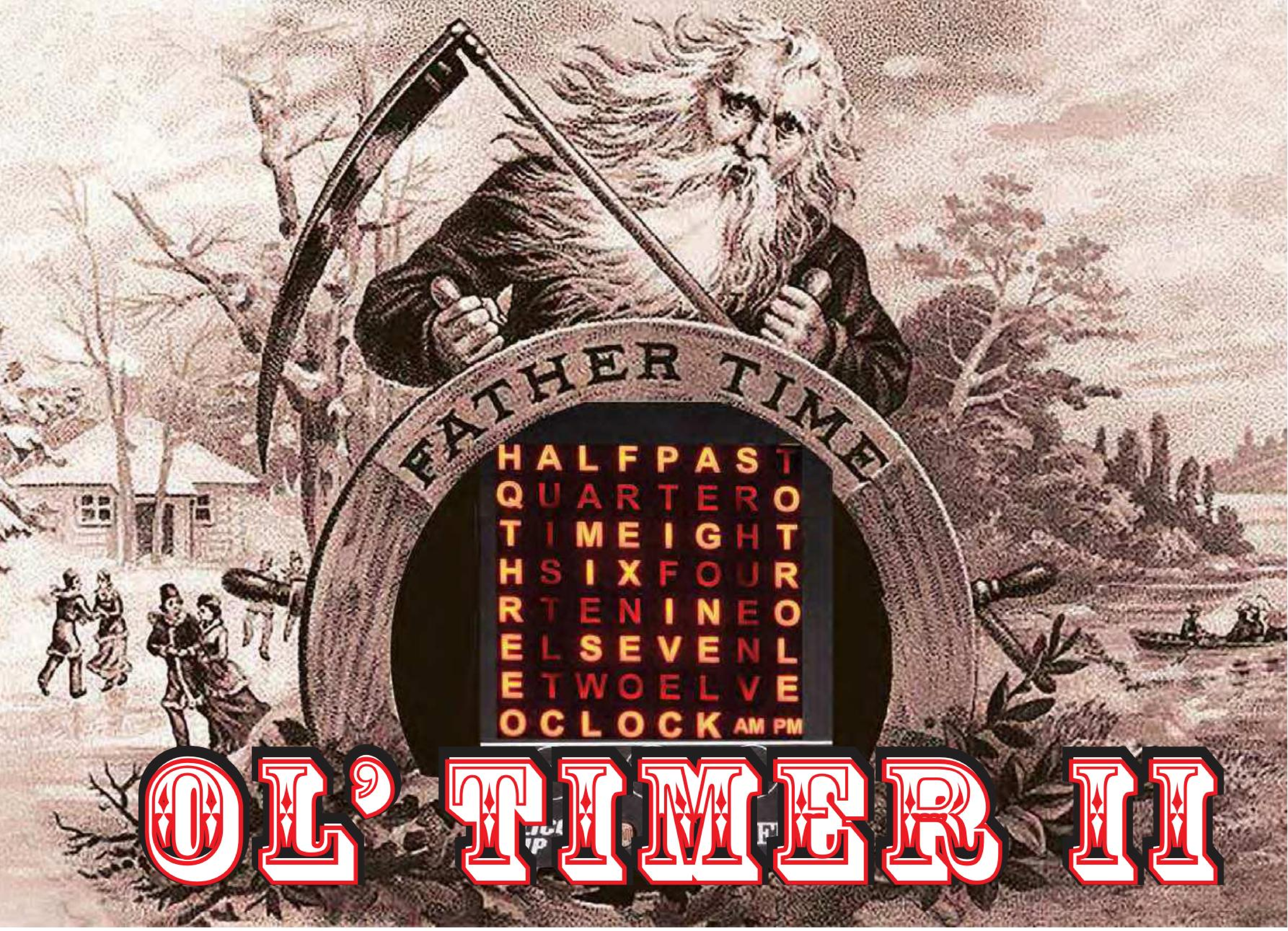


OL' TIMER II

Once upon a time, clocks were not very accurate. Nowadays, the time shown on your mobile phone or computer is probably accurate to a miniscule fraction of a second. If you're yearning for a more relaxed attitude to time, this project is for you!

by Tim Blythman

The digital clock in your mobile phone or computer is highly accurate and regularly updated, kept within a fraction of a second of an atomic clock standard via the Internet. But it hasn't always been like that.

When I visited my grandparents as a child, I remember the tall grandfather clock they had in their house. Aside from the minor ceremony of its weekly winding, it was practically hidden away and not easy to see, but frequently heard, as it had the type of chimes that would sound off the quarter hours.

On the hour, it would sound off the number of hours; in between, distinct chimes for each quarter-hour. It was easy to tell what the time was to the nearest fifteen minutes.

The *Ol' Timer II* recalls this more relaxed attitude to time while evoking a modern and stylish appearance.

Inspiration

This project was inspired by and named for the (old) *Ol' Timer* project from November 1994. It displayed the time as a combination of words and numbers and used a PIC16C57 microcontroller to control bitmaps on a 40×7 LED matrix.

Back in the day, we didn't need to know the time to the nearest second, and the manner of speaking the time reflected that. People would say, 'quarter to ten' or 'five o'clock' instead of 'nine-forty-five' or just 'five'.

The proliferation of digital clocks means some young people can't even read older analogue clocks, let alone understand this way of speaking the time.

But the *Ol' Timer II* displays the time in written words, expressed in this style. The display is only updated every fifteen minutes; this was partly a conscious design decision, and partly because we're limited by what fits on the chosen display.

So, if you prefer a relaxed and old-fashioned attitude to time, this clock is for you.

Design

Rather than using a graphical or character LCD, we have combined an 8×8 RGB LED matrix with a cleverly-designed PCB mask. This approach allows various combinations of letters to be displayed.

It's the sort of thing that could have been rigged up with a matrix of incandescent lamps controlled by clockwork. That is, if we were designing this in the 1920s rather than the 2020s!

So this is how words are displayed on the *Ol' Timer II*, although the choice of an RGB LED matrix means we aren't limited to illuminating the letters in an 'incandescent yellow' colour.

The RGB matrix is based on 64 WS2812B ICs which each contain red, green and blue LEDs plus a serially-controlled driver chip. We had a good look at this type of display in *PE's* January 2021 issue.

Circuit description

Refer to Fig.1, the circuit diagram. The *Ol' Timer II* is controlled by IC1, a PIC16F1455 8-bit microcontroller.

IC1's RC5 GPIO pin (pin 5) is configured as a digital output, and this drives the serial data input of the LED matrix via a 390Ω resistor and pin header CON3.

The other two pins on the three-pin display header supply 5V power to the 8×8 RGB LED matrix module, MOD1.

Details on how this serial data is used to control the colour and brightness of the 64 LEDs are in the article mentioned above. Suffice to say, these three lines are sufficient to power and control all the LEDs with individually settable 24-bit RGB colour values, giving 16,777,216 possible colours for each.

IC1's RC4 and RC3 general-purpose I/Os at pins 6 and 7 connect to the I^2C serial bus interface of IC2, a DS3231 RTC (real-time clock) IC. Although IC1 has a dedicated I^2C interface, its pins are shared with the programming header.

Since I^2C is easy to 'bit-bang' with direct port operations, we preferred to do it this way. Thus, IC2 cannot interfere with programming signals and vice versa.

We had enough free pins on IC1 to allow us to do this; and it also simplifies the PCB layout slightly.

The two I^2C lines are pulled up to 5V by a pair of 4.7kΩ resistors, as required by the I^2C specification.

IC1's pins 8, 9 and 10 (analogue pins AN6, AN5 and AN4 respectively) are connected to circular touchpads on the PCB.

We use the analogue-to-digital converter (ADC) peripheral to sense these pads being touched. A finger on any of the pads alters its capacitance slightly, changing the rate at which it charges or discharges via weak DC currents, enough to be detected by IC1.

These touchpads provide a way to set the unit up even if you don't have a computer with a USB interface handy.

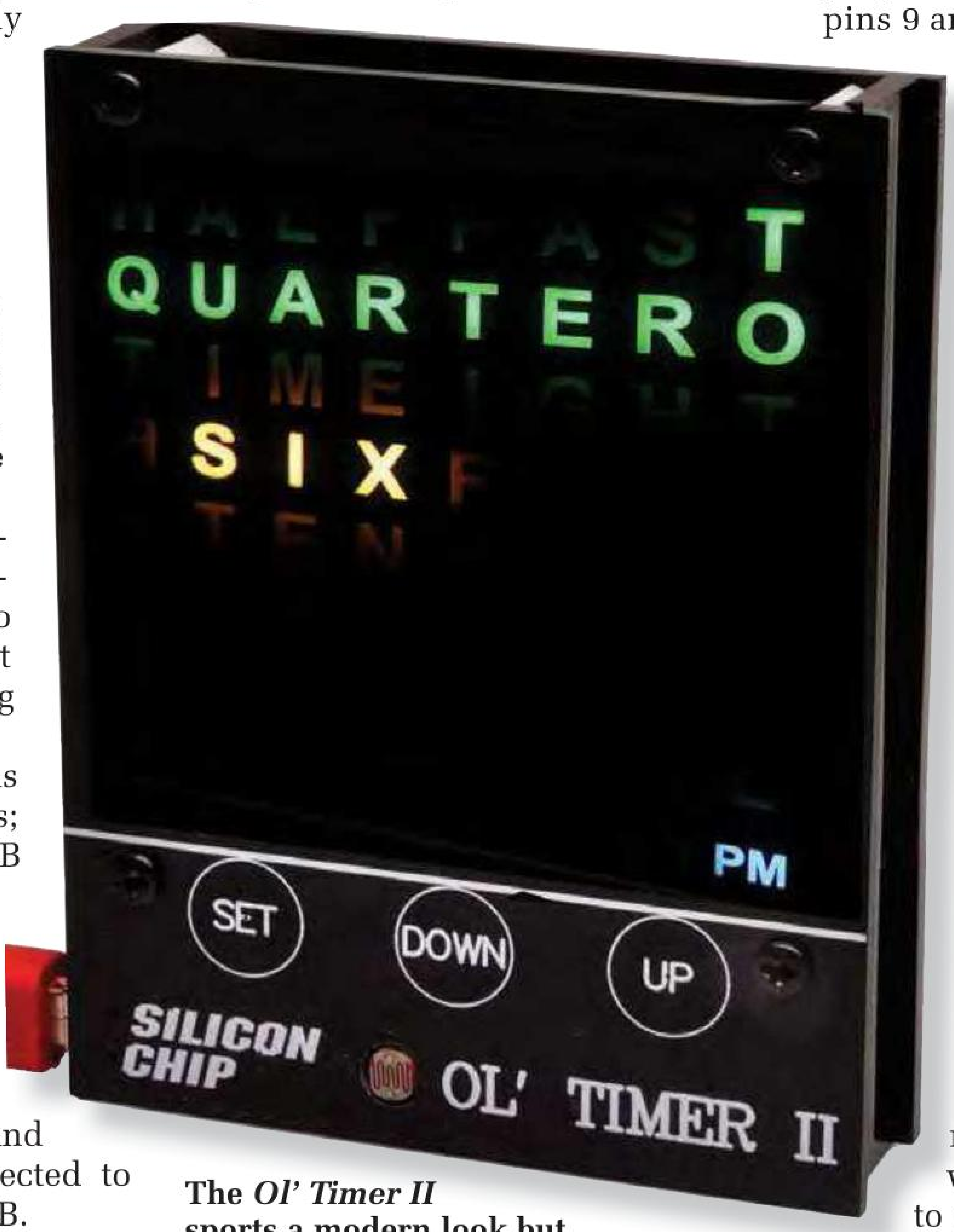
LDR1 has a resistance which changes depending on the light level falling on it. It is connected in series with a 1MΩ resistor across the 5V supply, and a 100nF capacitor smooths the resulting voltage, which is then fed to the AN3 analogue input (pin 3) on IC1.

When the LDR is illuminated, its resistance is of the order of 100kΩ, and the voltage at AN3 is around 4.5V.

In the dark, the LDR has a resistance of about 10MΩ, so the voltage on pin 3 is closer to 0.5V. The 100nF capacitor provides a low-impedance source for the AN3 analogue pin (pin 3), which reads this voltage and calculates a display-brightness level based on the ambient light level and the user settings.

IC1, IC2 and the LED matrix receive 5V DC power from CON1, a mini-USB socket. IC1 and IC2 each have 100nF local supply bypass capacitors.

The USB data lines on CON1 are also connected to the dedicated USB D+/D– pins (13 and 12) on IC1, allowing the device to be configured via a computer's USB port.



The *Ol' Timer II* sports a modern look but recalls an older way of reading the time. It's powered by 5V from a mini-USB socket, and the display colours are fully customisable.

Features

- Displays the time as words
- Uses a DS3231 real-time clock IC for accurate long-term timekeeping
- Compact and stylish
- LED colours are customisable
- USB-powered
- Setup via USB or integrated capacitive touch buttons
- Adjustable brightness with ambient light sensing

A 10kΩ resistor provides a pullup for IC1's $\overline{\text{MCLR}}$ pin (pin 4), allowing it to run whenever it is powered.

IC2 has support for battery backup power at its pin 14, which is connected to a button cell battery holder. It is intended to be fitted with a CR2032-type battery, so that the time is retained even when 5V power is removed.

Finally, IC1's in-circuit serial programming (ICSP) pins are wired to CON2 so that IC1 can be programmed after it has been soldered to the board. The required connections are 5V, GND, $\overline{\text{MCLR}}$, ICSPCLK and ICSPDAT (pins 9 and 10). Pins 9 and 10 have 100Ω series resistors to avoid damage to a programmer if it is connected while pins 9 and 10 are being driven.

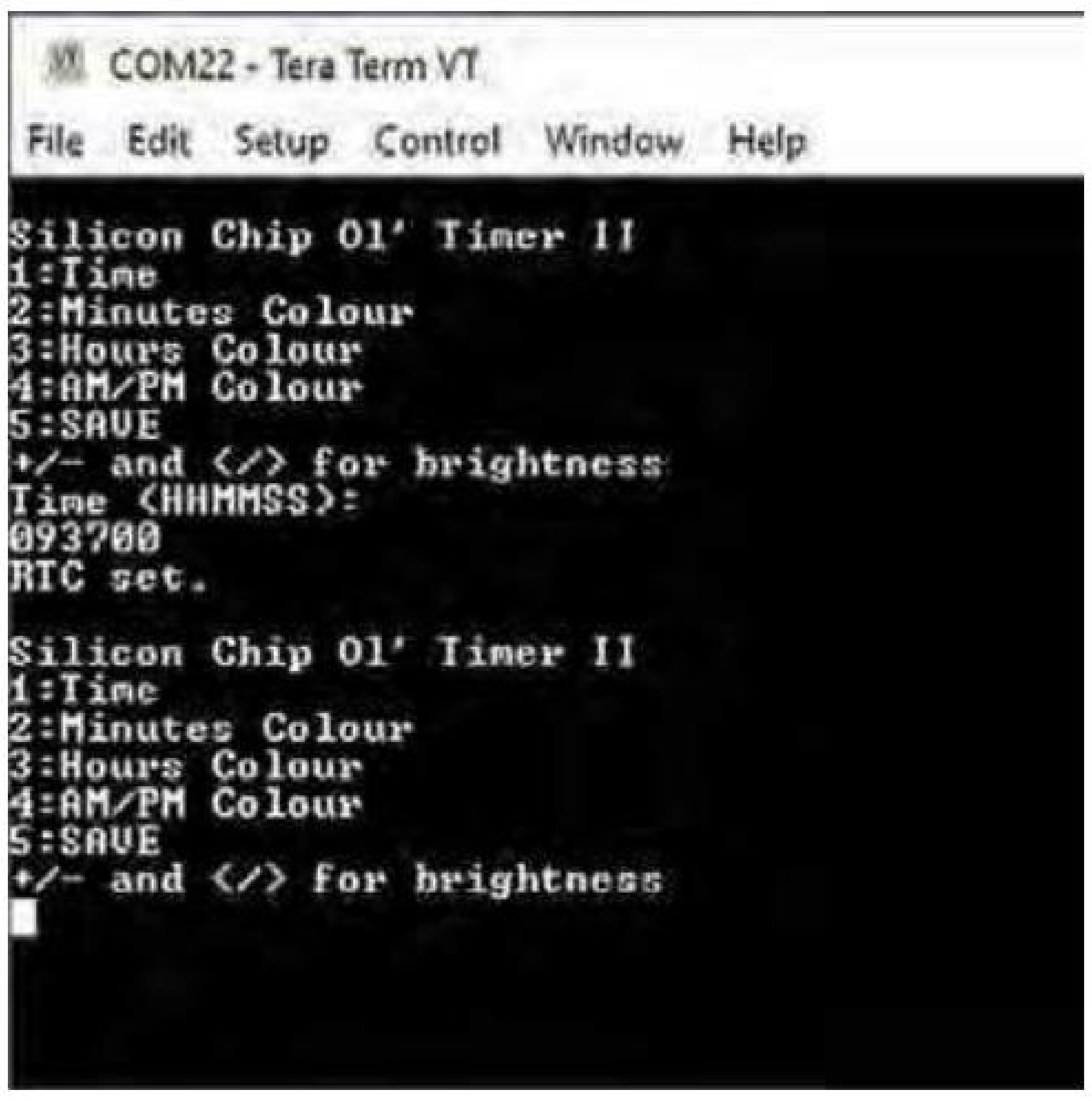
CON4 is not electrically connected to any part of the circuit, but is used to mechanically secure a corresponding set of pads on MOD1, the LED matrix PCB.

Operation

The general operation of the circuit is typical for microcontroller-based digital circuits and naturally depends heavily on the firmware we have written. IC1 checks the time by querying IC2 over the I^2C bus and then updates the display at CON3 as necessary.

As you might have seen from the article about these modules (and the individual LED chips used in them), the control signal is quite time-sensitive. Thus, we have written this part of the code in assembly language to guarantee the timing.

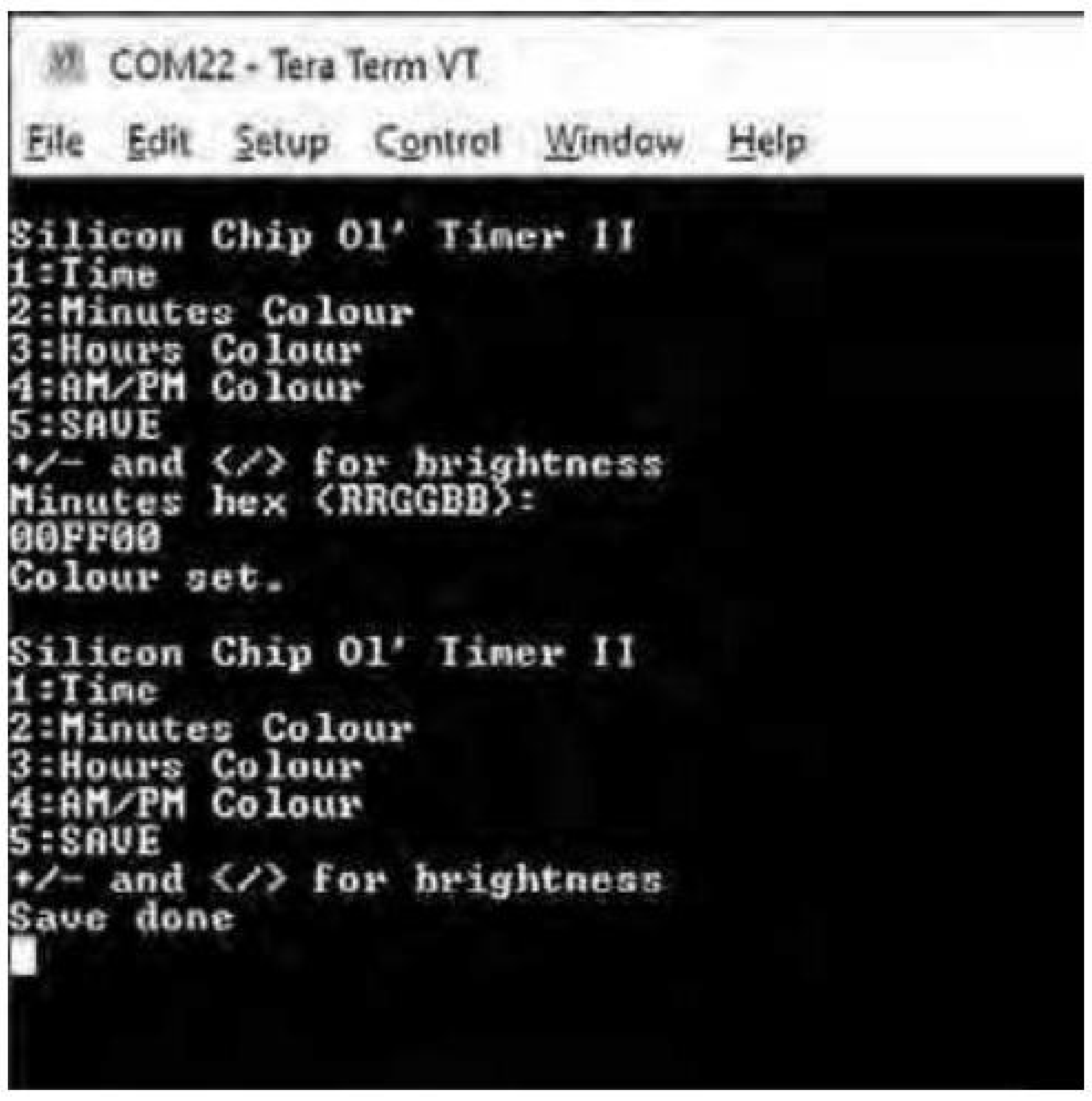
This includes turning off microcontroller interrupts while the data is being sent to the matrix. We were initially concerned that this might interfere with USB communications (it takes around 2ms to update all the LEDs), but we have not noticed any problems.



```
Silicon Chip Ol' Timer II
1:Time
2:Minutes Colour
3:Hours Colour
4:AM/PM Colour
5:SAVE
+/- and </> for brightness
Time <HHMMSS>:
093700
RTC set.

Silicon Chip Ol' Timer II
1:Time
2:Minutes Colour
3:Hours Colour
4:AM/PM Colour
5:SAVE
+/- and </> for brightness
█
```

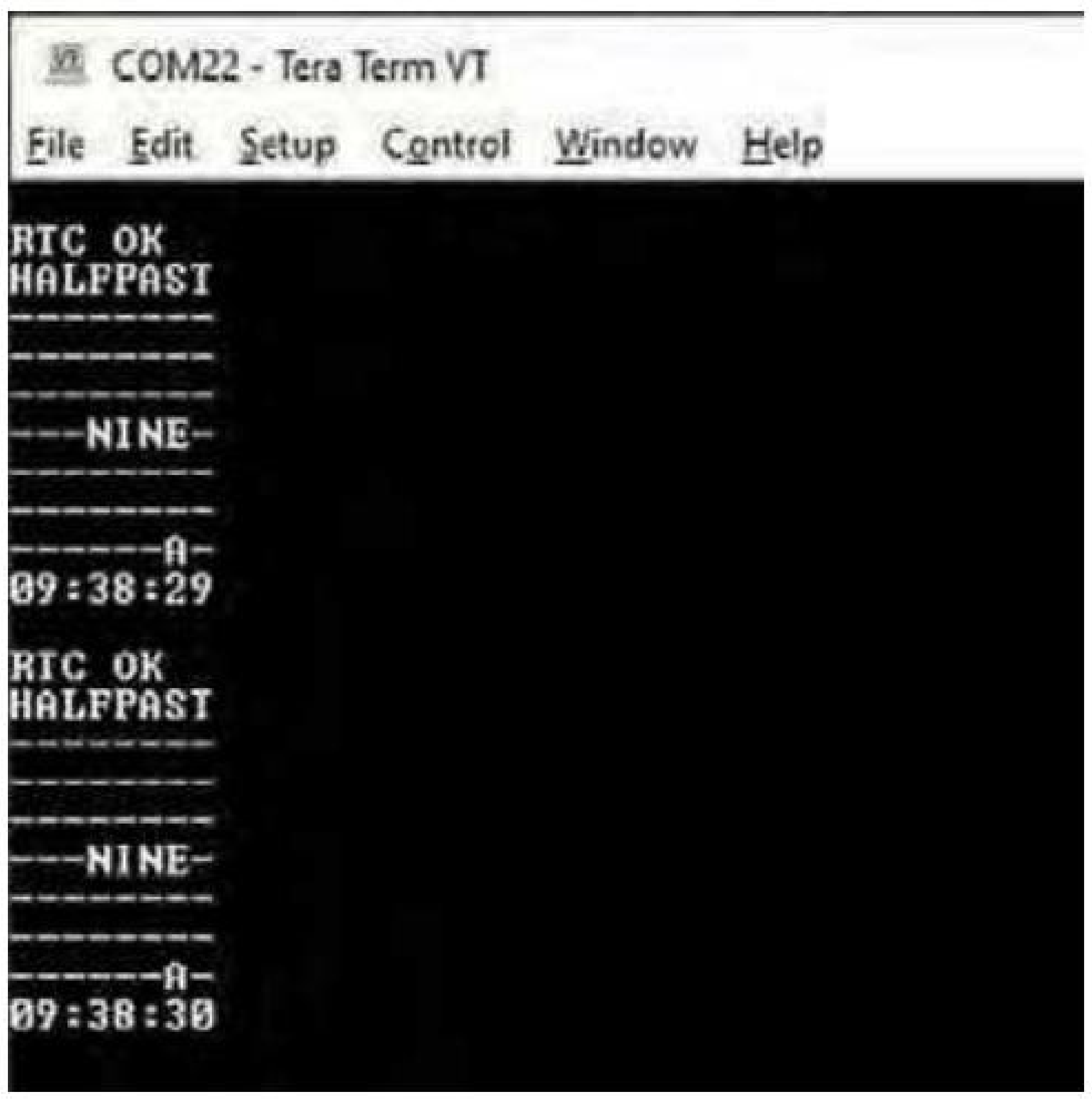
Screen1: the menu system offered over the USB-serial port is easy to use. Press Esc then 1 to set the time, followed by six digits in 24-hour HHMMSS format.



```
Silicon Chip Ol' Timer II
1:Time
2:Minutes Colour
3:Hours Colour
4:AM/PM Colour
5:SAVE
+/- and </> for brightness
Minutes hex <RRGGBB>:
00FF00
Colour set.

Silicon Chip Ol' Timer II
1:Time
2:Minutes Colour
3:Hours Colour
4:AM/PM Colour
5:SAVE
+/- and </> for brightness
Save done
█
```

Screen2: display colours can be set with menu options 2, 3 and 4, in the standard 'web' format of a six-digit hexadecimal colour code in RRGGBB order. The colour shown here (00FF00) is pure green.



```
RTC OK
HALFPAST
--------
--------
--------
---NINE-
--------
--------
------A-
09:38:29

RTC OK
HALFPAST
--------
--------
--------
---NINE-
--------
--------
------A-
09:38:30
```

Screen3: pressing Q at any time starts a debugging output display which can be stopped by pressing Esc. The RTC status, digital time and intended LED display are shown and updated every second.

IC1's USB peripheral does all the time-critical work independently in hardware; so as long as the software doesn't delay too long, it works fine.

As briefly described above, the three touchpads are probed using the shared capacitance technique. The detail behind this method is explained in a panel in our *ATtiny816 Breakout Board* article that we published in last month (July 2021). Essentially, the change in capacitance from finger proximity can be measured by clever use of the ADC (analogue-to-digital converter) peripheral. So we have been able to add three 'pushbuttons' without any extra hardware, apart from some PCB tracks.

At the back of the PCB, on the reverse of the touchpads is a copper ground pour. This, combined with the shape chosen for the touchpads, maximises the capacitance change that occurs when it is touched.

These three pads can be used to set the time and alter the clock configuration, with the SET button cycling between several parameters and the UP and DOWN buttons allowing the parameters to be changed.

The USB peripheral on IC1 is also programmed in firmware to behave as a USB-serial bridge. When connected to a serial terminal program, an intuitive configuration menu can be accessed to change the time and other clock settings.

Display

That we have used a microcontroller to control the LED matrix is straightforward enough, but we think the clever part is how the matrix is used to create a readable output capable of displaying words.

Most of the PCB is actually a carefully crafted mask intended to transmit the shape of the letters. Where we want light to shine through, the solder mask and copper layer have been removed, meaning that light from the LED underneath is only diffused by the FR4 fibreglass material in between.

The top copper layer forms a solidly opaque mask, and the solder mask gives a uniform appearance (the alternative here would be a bright silver layer of solder). To reduce spillover from adjacent LEDs, an acrylic mask sits around each LED, further limiting the spread of light.

Since each LED can be lit up to practically any colour in the RGB spectrum, we can illuminate each letter a different colour to differentiate the words, or set the brightness to account for different viewing conditions.

This basic concept is not new, but most of the similar designs we have seen use a much larger matrix. We felt that 8×8 should be enough.

Laying out the letters to display the necessary words was the tricky part. We managed to fit everything in with the help of a spreadsheet, although we did have to fit some words in vertically, which is not something we'd seen done before.

We had a few LEDs left over which were not needed to form any of the words, so we have allocated them to other useful features. The last two 'pixels' at bottom right were free and are well suited to an AM/PM display, so the masks have been designed to show these pairs of letters in a slightly smaller font.

With some clever use of the existing letter layout, some other words can be displayed, if necessary, although the software does not make use of this.

The matrix can also be used as individual pixels, so we can also display some small bit-mapped numbers if necessary. We use this to display information when the colour or brightness is being updated by the touchpad controls.

Construction

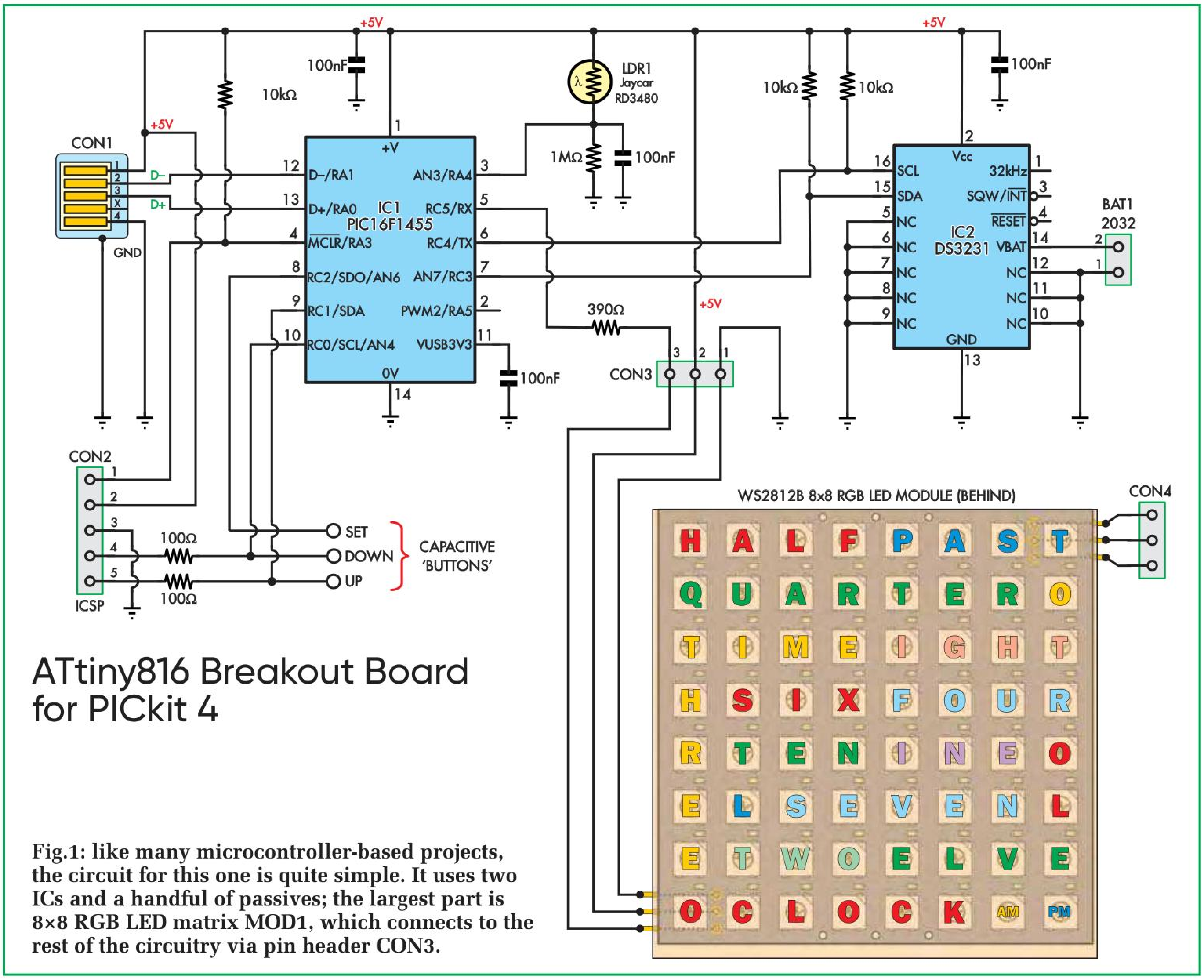
Like many projects, this one depends on surface-mounted components; not so much due to size, but because it allows the front of the PCB to be unmarred by soldered pads. As such, we suggest that you have some solder flux paste, braid (wick), tweezers and a magnifier on hand, along with a soldering iron, preferably one which can have its temperature adjusted.

The flux generates a moderate amount of smoke, so use a fume extractor or work outside if possible to avoid breathing in the fumes. A fine-tipped iron is helpful, but even a chisel tip held with its edge vertically should be OK to do the job. We used a 2.4mm chisel tip to build our prototype.

Refer to the PCB overlay diagrams (Fig.2) during construction. The clock is built on a 77 × 99mm PCB, coded 19104201 and available from the *PE PCB Service*. Start with the components that mount on the back. Specifically, solder CON1 first because its pins are somewhat difficult to access. We've extended its PCB pads to make soldering it slightly easier.

Apply some flux paste to the pads for the USB socket, turn your iron up slightly (if it's adjustable) and line up the socket; the locating pins go into holes on the PCB to aid alignment. Solder one of the larger mechanical pads on the body, ensuring that the electrical pads are flat against the PCB.

Load up the tip of the iron with a small amount of fresh solder and place it on each PCB pad in turn, adding some solder to the tip between pins. The flux


+5V
100nF
10kΩ
LDR1
Jaycar
RD3480
1MΩ
100nF
10kΩ
10kΩ
+5V
100nF
CON1
D–
D+
GND
+V
D–/RA1
D+/RA0
IC1
PIC16F1455
MCLR/RA3
RC2/SDO/AN6
RC1/SDA
RC0/SCL/AN4
0V
AN3/RA4
RC5/RX
RC4/TX
AN7/RC3
PWM2/RA5
VUSB3V3
100nF
390Ω
+5V
CON3
SCL
SDA
NC
Vcc
IC2
DS3231
GND
32kHz
SQW/INT
RESET
VBAT
BAT1
2032
CON2
ICSP
100Ω
100Ω
SET
DOWN
UP
CAPACITIVE 'BUTTONS'
WS2812B 8x8 RGB LED MODULE (BEHIND)
CON4
H A L F P A S T
Q U A R T E R O
T I M E I G H T
H S I X F O U R
R T E N I N E O
E L S E V E N L
E T W O E L V E
O C L O C K AM PM

ATtiny816 Breakout Board for PICkit 4

Fig.1: like many microcontroller-based projects, the circuit for this one is quite simple. It uses two ICs and a handful of passives; the largest part is 8×8 RGB LED matrix MOD1, which connects to the rest of the circuitry via pin header CON3.

will induce the solder to run off the iron and onto the pins.

Inspect your work with a magnifying glass; it will be much easier to correct this now without other components in place. Use the braid and iron to remove any excess if there is a bridge. There isn't much room to do this, so take your time. Once you are happy with the socket's pins, solder the remaining mechanical tabs. The iron can be turned back to its regular setting after this.

Fit the ICs next. IC1 is the smaller, 14-lead part. Apply some flux to the IC's PCB pads and rest the IC on its pads. Check that the pin 1 dot is adjacent to the dot marked on the PCB. Solder one corner pin in place and check that the remaining pins are flat and within their pads. If not, soften the solder with the iron and adjust until they are.

Solder the remaining pins, adding solder to the iron as you go. If you make a solder bridge, leave it for now and ensure that the pins are all soldered before correcting. This will ensure that the IC stays in the correct place.

Use the braid and iron (and extra flux if necessary) to remove any excess solder which is bridging between pins. The technique we use is to apply the flux to the top of the bridge, then press the braid against it using the iron. Gently draw the braid away from the pins after the solder melts and is drawn into the braid.

IC2, the wider 16-pin part, has a similar treatment. Check its orientation then solder one pin. Once it is in the correct location, solder the remaining pins and remove bridges as necessary.

There are four identical 100nF capacitors. They will have no markings and are not polarised. Refer to our photos, the overlay and PCB silkscreen to see where they fit. As with the ICs, apply flux, solder one pin in place, check that it is square, flat and flush against the PCB before soldering the remaining pin.

There are a few different resistor values, so check these against the PCB markings, the photos and Fig.2 before fitting them.

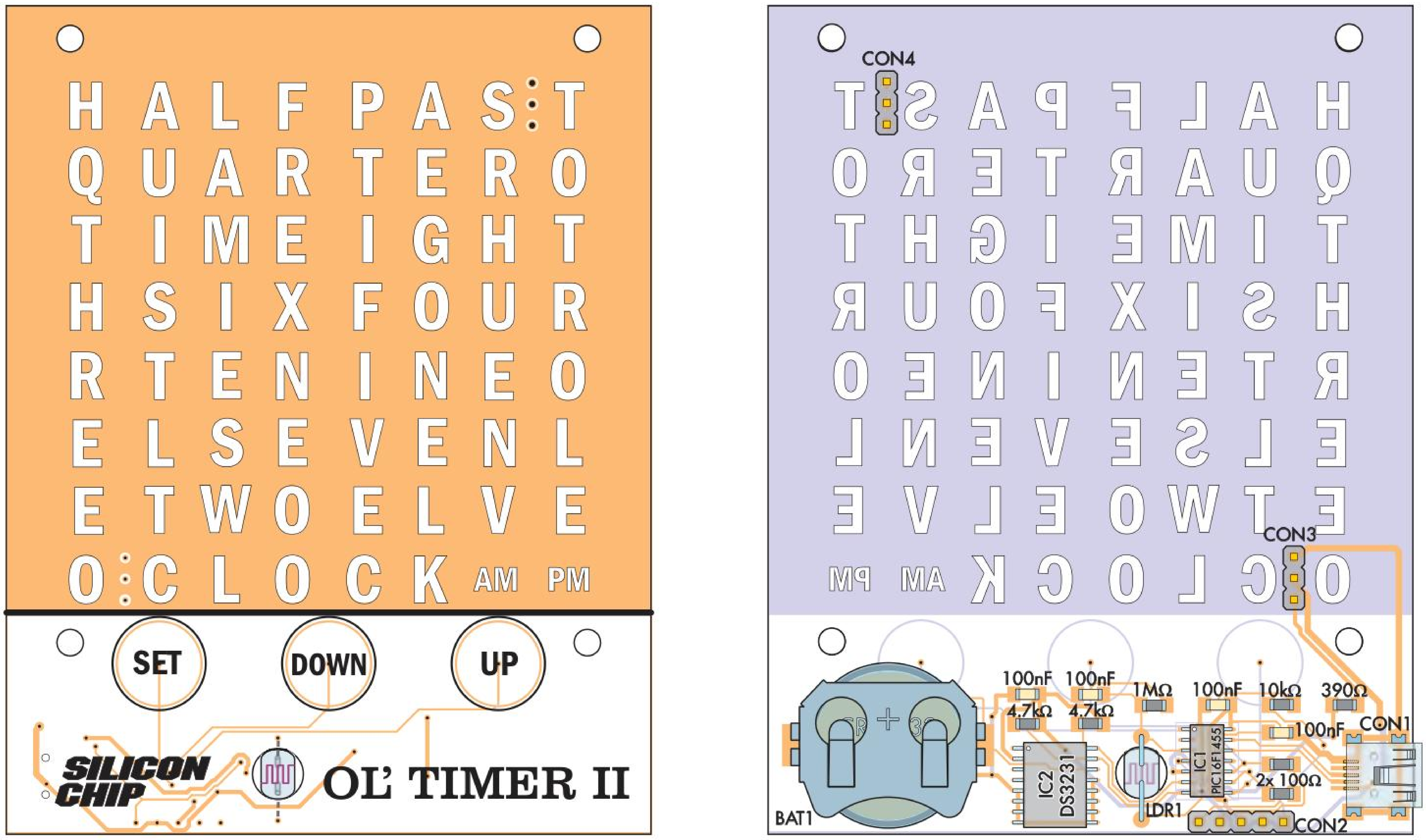
The LDR is a through-hole part, but we have to mount it in an unorthodox fashion to fit in with the other parts. Have a look at the overlay and photos as you read through the explanation.

Sit the PCB face-down on a flat surface, bend the LDR's leads by 90° and place it in the centre of the hole marked LDR1 with the leads aligned vertically. It's not polarised, so it doesn't matter which way it is rotated. Mark on the leads where they cross the pads on each side of the hole, then trim one, using the other to position the part.

Place the LDR back in the hole and solder the shortened lead in place to the adjacent pad. Flip the PCB over and check that the appearance is acceptable and that the LDR is centred and parallel to the PCB before trimming and soldering the remaining lead. It's easier to bend and adjust the leads while only one is soldered.

The battery holder is a larger part, so you might like to turn the iron temperature up. Apply some flux paste to the pads and sit the battery-holder (BAT1) over the top. Ensure that the opening is at the edge of the PCB to allow the battery to be fitted or removed. As for the other parts, solder one pad, then check the alignment and then solder the other pad.

If you need to program IC1 in-circuit, then you can solder a header for CON2



FRONT VIEW

REAR VIEW (WITHOUT RGB LED MODULE)

Fig.2: follow these top and bottom side PCB overlay diagrams during construction. Most of the PCB does not have components installed; it is used as a mask for the LEDs. Since virtually all components are on the back, the letter mask appears backwards in that view. Fit the USB socket, then the ICs, followed by the passives. The battery holder and LED module come last.

as we have done. But this is not strictly necessary as it is possible to simply hold the header in place during programming. There are small vias on the pads which help keep the header aligned.

We should point out that while they are through-hole parts, none of the headers (CON2-CON4) are soldered in the regular manner. Instead, they are vertically surface-mounted onto a set of pads.

In each case, first insert it into a header socket to keep the pins together and aligned (and also provide something to hold onto, as the header will get hot!).

Put some solder flux on the pads and rest the header approximately where it needs to go. Solder one pin in place and check the alignment. If it is only slightly off, you might be able to gently flex it before soldering a pin at the other end of the row, but don't flex it too hard, or it might tear the pads from the PCB.

For CON2, once it is in position, solder the remaining pins of the header and then remove the header strip. For CON3 and CON4, you should check that MOD1 is correctly aligned before soldering the remaining pins.

So once you've tacked CON3 and CON4 in place, check for squareness by trying to fit the LED matrix module over the top. It's also a good idea to test-fit the acrylic mask piece to ensure that everything is aligned before soldering all the header pins. Once they've been fitted, slide the acrylic mask piece over the pins, then fit MOD1. This is then soldered to CON3 and CON4.

It will be tricky to undo this, so take extra care in ensuring that the two boards are parallel and as close together as possible. We tacked one pin, then firmly squeezed the boards together while remelting the solder, allowing the gap to close. Note that the PCB and module won't quite be flush because the LED module also has small capacitors on its surface.

Programming

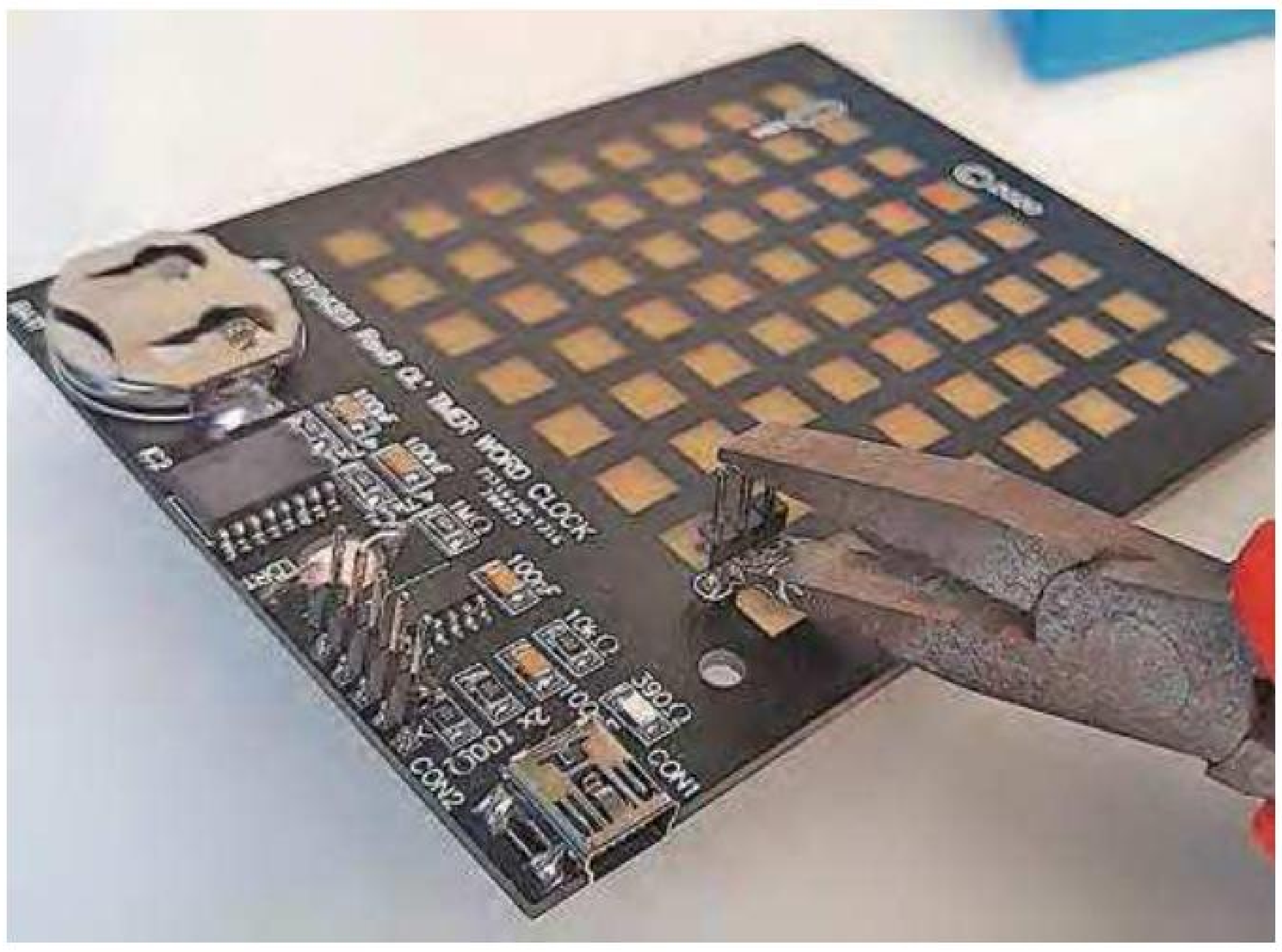
You don't need to program IC1 if you purchased it pre-programmed. But if you have a blank micro, you need to program its Flash memory with the firmware HEX file to get the clock to work correctly. Download this from August 2021 page of the *PE* website before proceeding and extract the HEX file from the ZIP package.

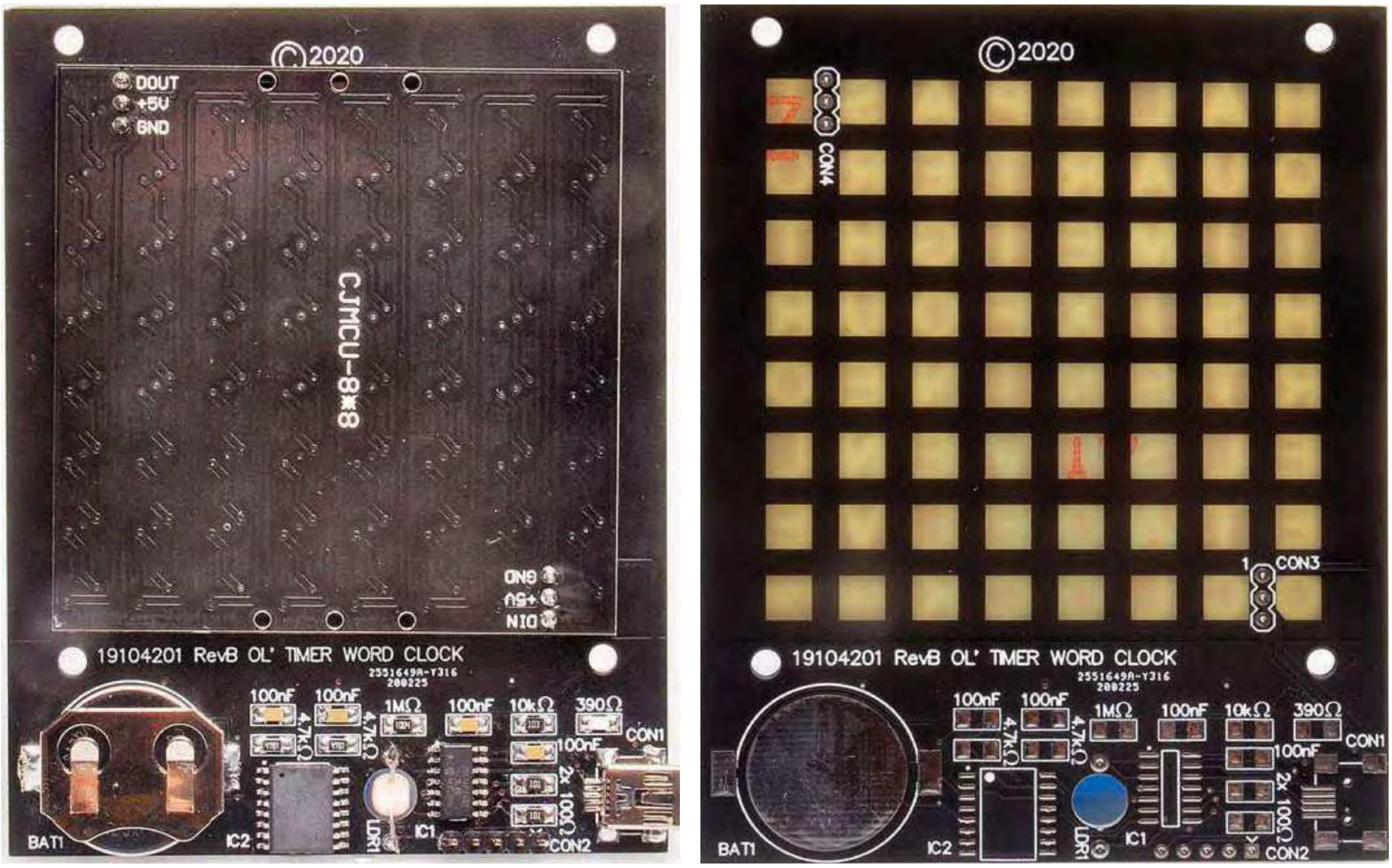
You can use a PICkit 3, PICkit 4 or Snap programmer to do this. We used a Snap, but since this does not provide power, you will need to supply power via a USB cable plugged into the USB socket.

Note that the Snap cannot perform high-voltage programming, so if IC1 has had its LVP (low-voltage programming) fuse bit set, the Snap can't clear it. But it will work with a new, blank chip.

Plug your programmer into the ICSP header (CON2). Its pin 1 is closest to the USB socket and marked with a small arrow. If you have not soldered the header for CON2, merely plug a male header

To remove the plastic holder from the pin headers (after soldering to the main PCB), carefully place a pair of pliers as shown and squeeze. You should repeat this procedure for CON4 too, before soldering MOD1 in place.





At left is the populated PCB with the LED Matrix (MOD1) fitted above. Not seen is the acrylic mask that sits between the two. The photo at right shows the gaps in the solder mask which allow the light to shine through.

strip into your programmer and hold it against the pads of CON2.

We recommend that you use the free Microchip MPLAB X IPE (integrated programming environment) software. Windows, Linux and Mac versions are available from **www.microchip.com/mplab/mplab-x-ide**

The PIC16F1455 is an 8-bit part, so install support for 8-bit parts if queried. Open the IPE, select 'PIC16F1455' as the device and choose your tool from the drop-down below this. Select 'power target circuit from tool' if you aren't providing 5V via the USB cable. But do not do both.

Click 'Apply', then 'Connect'; the IPE should indicate that it has found a PIC16F1455 device. You can then use the browse button opposite the Hex File option to choose the .HEX file that you downloaded earlier. Click 'Program' to write the .HEX file into the chip's Flash memory.

If you run into problems, check that the programmer settings are correct and ensure that power is supplied from either the programmer or a USB cable, but *not* both. Also, check that your programmer is making good contact with CON2. If holding the header to the board, it might work if you try again.

Setup

If you haven't already done so, connect the clock to a computer using a mini-USB cable. The first time it's powered up (ie, with IC2's time unset), it should light up showing the words, 'TWELVE OCLOCK AM'.

The clock uses the same IC and USB-serial profile as the *Build the Microbridge* project from May 2018. If you need drivers (which should not be necessary under Windows 10, Mac or Linux), then suitable drivers can be downloaded from **www.microchip.com/wwwproducts/en/MCP2200**

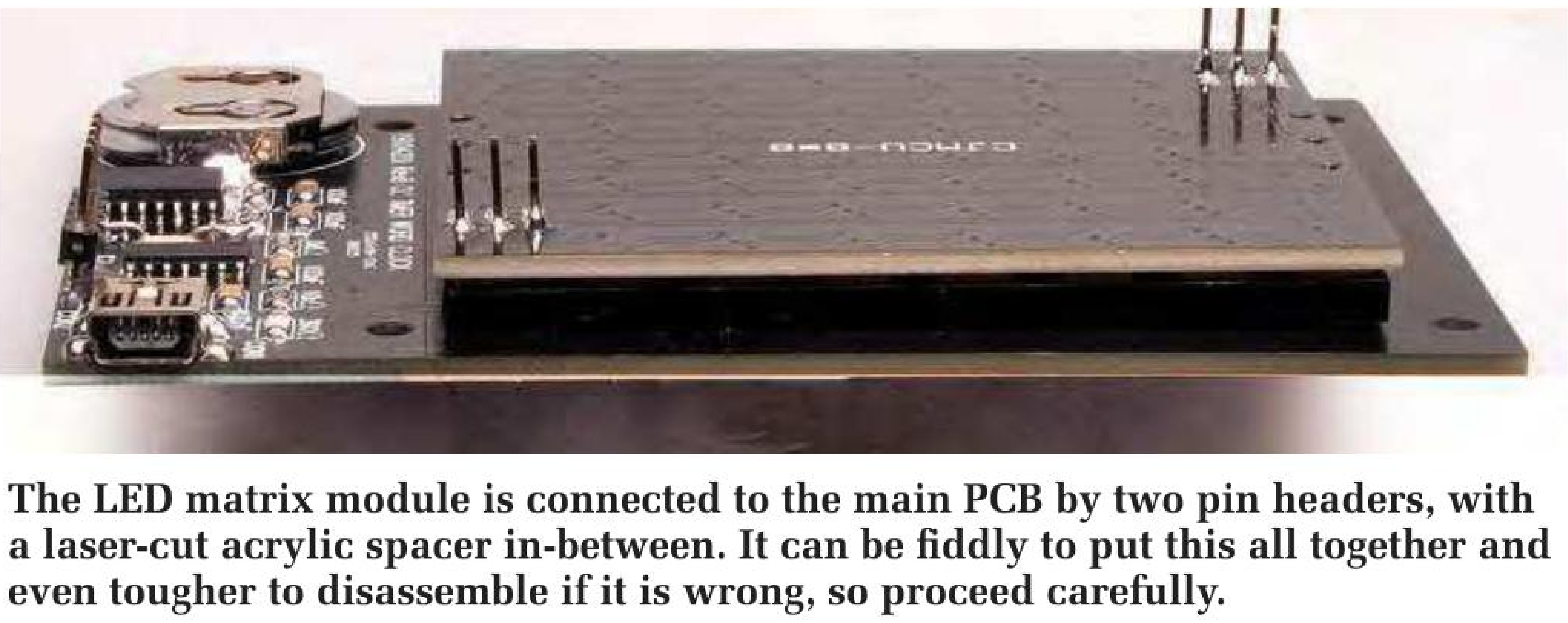
You will need a serial terminal program to complete the setup. We used TeraTerm, although most serial terminal programs, including PuTTY (but not the very limited Arduino Serial Monitor) should work.

Find the device's port and open it. You do not need to worry about the baud rate as the clock uses a virtual serial connection that ignores that setting. Once connected, pressing the Esc key should bring up the menu.

If at any time you don't know what the setup program is doing, press Esc to return to this point and abort any entry. Refer to screengrabs Screen 1-3 during the setup process. The prompts and responses are quite intuitive.

The first option, '1', sets the time. Press Esc, 1 and then the time in HHMMSS 24-hour form, then press Enter. The time is immediately saved to IC2 and the time display is updated. For example, to set the time to 3:30pm, type the digits '153000' when prompted.

There are also three colours that can be set, for the hours, minutes and AM/PM. These are entered as six-digit hexadecimal codes in the form RRGGBB. These sorts of codes are commonly used on webpages, so are easy to find, even if you don't speak hexadecimal!



The LED matrix module is connected to the main PCB by two pin headers, with a laser-cut acrylic spacer in-between. It can be fiddly to put this all together and even tougher to disassemble if it is wrong, so proceed carefully.

Parts list – Ol' Timer II

1 double-sided PCB coded 19104201, 77 x 99mm [From PE PCB Shop]
1 8x8 RGB LED module using WS2812B or similar (MOD1) [19104201-88 From PE PCB Shop]
1 set of acrylic case pieces and spacer [19104201-ACR From PE PCB Shop]
1 ORP12 or similar LDR (LDR1) [Jaycar RD3480, Altronics Z1617]
1 SMD button cell holder to suit CR2032 (BAT1)
1 CR2032 lithium cell (BAT1)
4 100nF 50V X7R SMD capacitors, 3216/1206 size *Code 104*
1 SMD mini type-B USB socket (CON1)
1 5-way male pin header (CON2, optional)
2 3-way male pin headers (CON3,CON4)
8 M3 x 6mm machine screws
4 M3 tapped 15mm nylon spacers

Semiconductors
1 PIC16F1455-I/SL 8-bit microcontroller programmed with 1910420A.hex SOIC-14 (IC1)
1 DS3231 real-time clock IC, wide SOIC-16 (IC2) [19104201-RTC From PE PCB Shop]

Resistors (all 1% SMD, 3216/1206 size)
1 1MΩ *Code 105*
1 10kΩ *Code 103*
2 4.7kΩ *Code 472*
1 390Ω *Code 391*
2 100Ω *Code 101*

We've listed a few common colour codes in Table 1; these are taken from the officially named HTML colours. If these are not suitable you may find the website **https://htmlcolorcodes.com/** quite helpful for generating and listing codes.

Thus, to set the colour of the minutes display to red, you would press ESCAPE, 2, FF0000 and press Enter. The colour change takes effect immediately, but does not get saved to non-volatile memory. This is only done when needed to reduce wear and tear on the Flash memory.

If you make an error while typing, you can use Delete or Backspace to remove the last character, or press Esc to abort and jump back to the main menu.

There are two different brightness settings. One of these corresponds to the brightness under low light conditions and is controlled by using the '+' and '–' keys. These can be pressed at any time to alter the brightness, no matter what the menu is doing.

The '<' and '>' keys control brightness under higher ambient light conditions, and they operate similarly. We found that in indoor conditions, quite low levels were comfortable, so we set the defaults quite low. The software prevents the level being set so low that the display is invisible.

The software does not manage the current drawn by the clock, nor make requests for power above the 100mA default set by the USB standards. We found that the normal clock display at default brightness levels sat just under 100mA, and rose to near 500mA with the brightness set high during setup (when more than the usual number of segments are lit).

With the brightness set this high, the display is almost too bright to look at, so lower levels are quite adequate.

Still, this shouldn't be a problem, especially if the clock is to be powered by a 'dumb' USB charger. Even if left connected to a computer, most USB ports will supply 500mA without complaining, enough to run the clock.

Table 1
Common hexadecimal colour codes

Aqua	00FFFF	Orange	FFA500
Blue	0000FF	Pink	FFC0CB
Brown	A52A2A	Purple	800080
Crimson	DC143C	Red	FF0000
Cyan	00FFFF	Salmon	FA8072
Gold	FFD700	Sky blue	87CEEB
Grey	808080	Tan	D2B48C
Green	008000	Teal	008080
Indigo	4B0082	Violet	EE82EE
Lime	00FF00	White	FFFFFF
Maroon	800000	Yellow	FFFF00
Navy	000080		

The colour codes here are drawn from the standard HTML colours used on web pages (we don't 'agree' with some of the name choices, but they give you some idea). Note that they may look different on the clock due to the PCB fibreglass colour and surrounding solder mask.

To set the clock brightness to work with a full range of lighting conditions, put the clock in a dark room (what it would be typically exposed to, say, at night) and set the 'low' brightness to a comfortable level using + and –. Then expose the Clock to daytime illumination and set the 'high' brightness with the < and > keys.

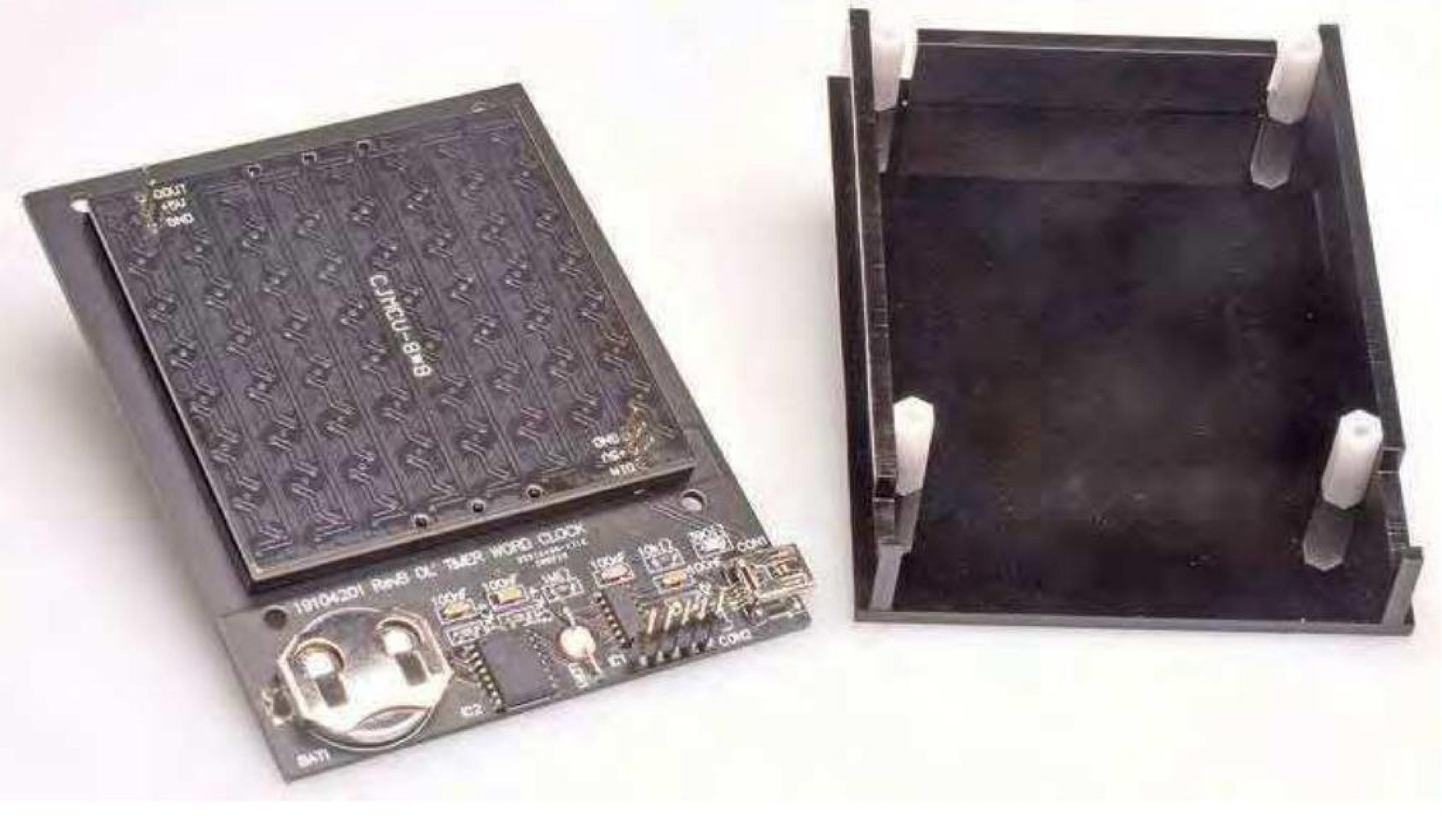
Check that the clock now responds correctly under all light conditions and tweak these further if necessary; the 'low' and 'high' levels will interact to a small degree so you may need to iterate this process a few times.

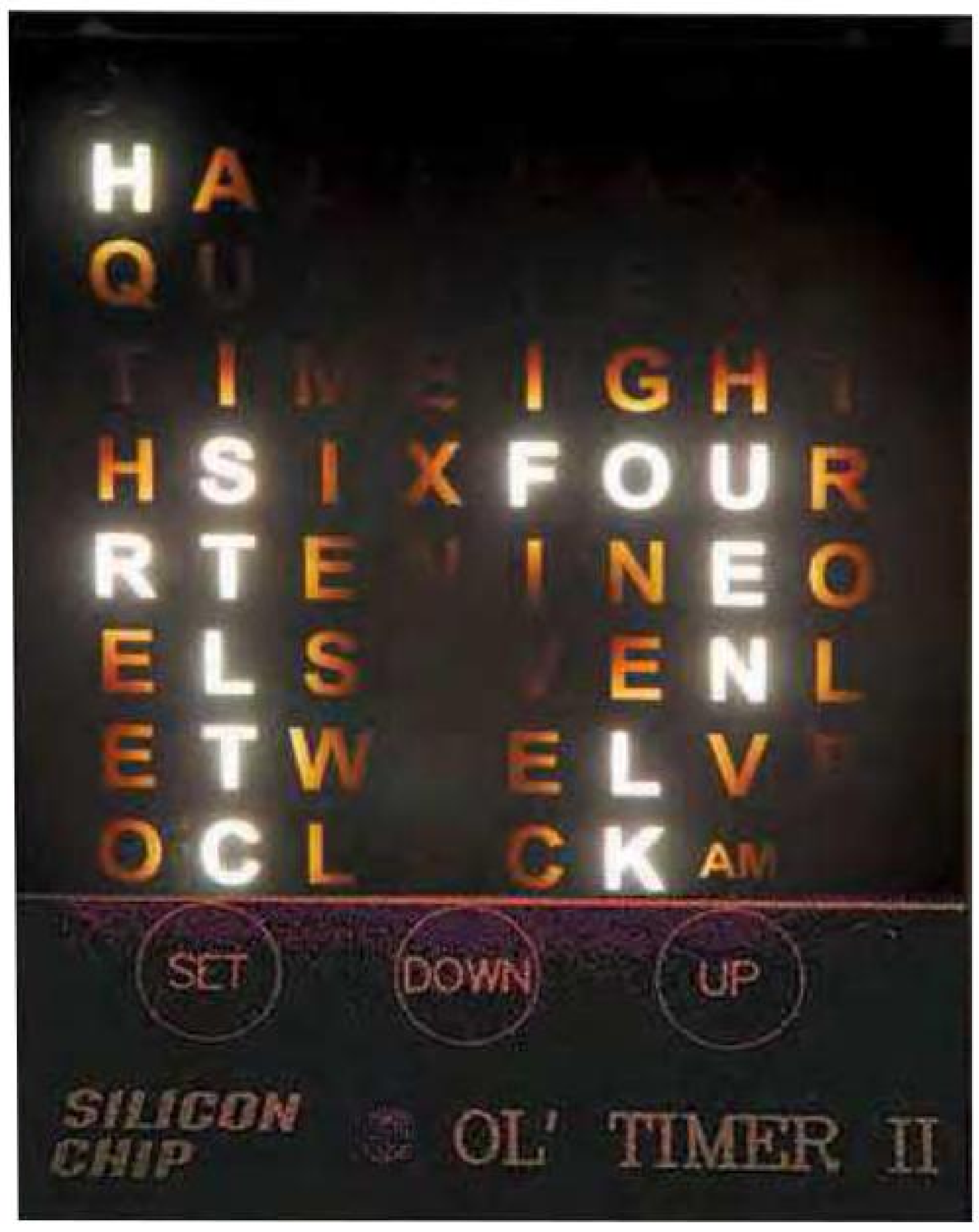
To save the colour and brightness settings, press Esc and then 5 as per the menu prompt. The current settings are saved to Flash memory and will now be loaded every time the clock powers up.

The serial interface has one more trick. If the 'q' key is pressed, the debugging mode is turned on. It can be turned off by pressing 'q' again or pressing Esc.

The result is shown in Screen3; the current time, RTC status and intended

The case pieces are assembled from back to front; the spacers are fitted to the back panel before the side pieces are slotted in place, with the main PCB being screwed in from above.



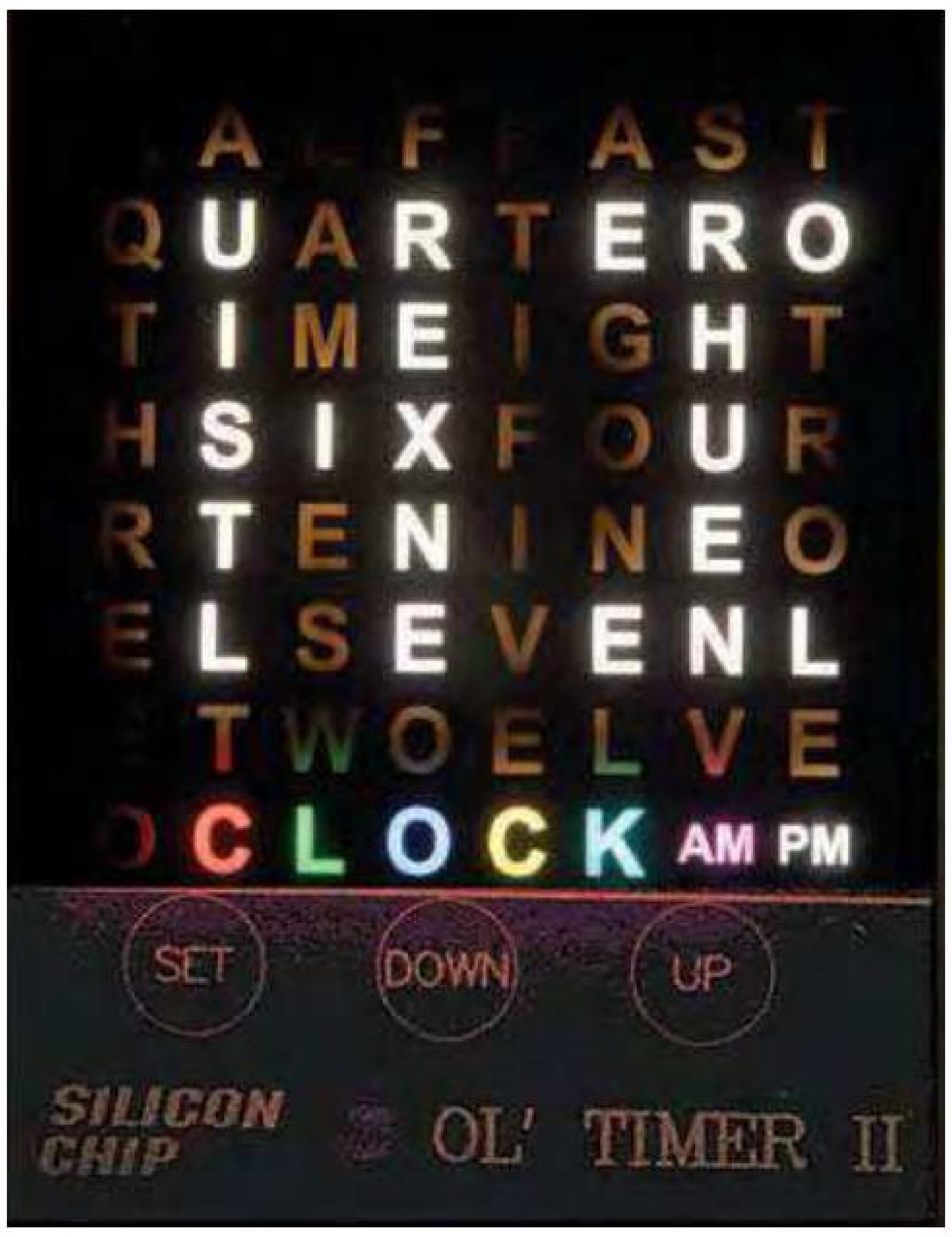


In setting the hours, minutes and seconds, either an H, M or S is seen along with the value as a decimal number (17 here). The real-time clock is updated after you leave the seconds setting.

LED display is scrolled and updated every second. If the unit's display does not look right, this will give you an indication as to what the problem might be. Or, if the time does not appear to be saved or loaded correctly, you will know whether RTC chip IC2 is functioning correctly.

Touchpads

If you don't have access to a computer or USB terminal program, all these parameters can be set using the touchpads. There are fourteen parameters set in turn; these are cycled by pressing the SET touchpad. The current parameter is changed by using the UP and DOWN touchpads.



The two brightness settings HI and LO are also set in hexadecimal, although you should simply adjust the level to be comfortable. A palette at the bottom indicates how some colours will look.

The pads have to be pressed quite firmly; we deliberately avoided making it too sensitive as it would be quite annoying to have the settings change unintentionally. If you have trouble, then try slightly moistening your finger.

The values are shown in decimal for time and hexadecimal for other numeric values (colour and brightness). Apart from the numeric display, some other LEDs are lit to let you know what is being set.

The first three parameters (in order) are the time in hours, minutes and seconds, with the letters H, M or S being shown to indicate this.

After the seconds are entered, the time is saved. If you make a mistake, the best option is to remove power for a second; there is no other way to avoid saving the time.

This is followed by the hours colour (red, followed by green, then blue) components. The minutes colour and then AM/PM colour follow. The component is shown by, for example, a red H or blue O (for other; ie AM/PM). The top-right LED (a T) shows how the mixed red, green and blue components look.

This is followed by the low brightness 'LO' and the high brightness 'HI'. A palette along the bottom line shows how different colours would look at these brightnesses. The photos on this page show these different displays.

A fifteenth screen shows a red (floppy disk!) save icon. If the UP or DOWN buttons are pressed when this is showing, the colour and brightness settings are saved to Flash.

Thus, all the parameters can be set, even if you don't have access to a computer or terminal program.

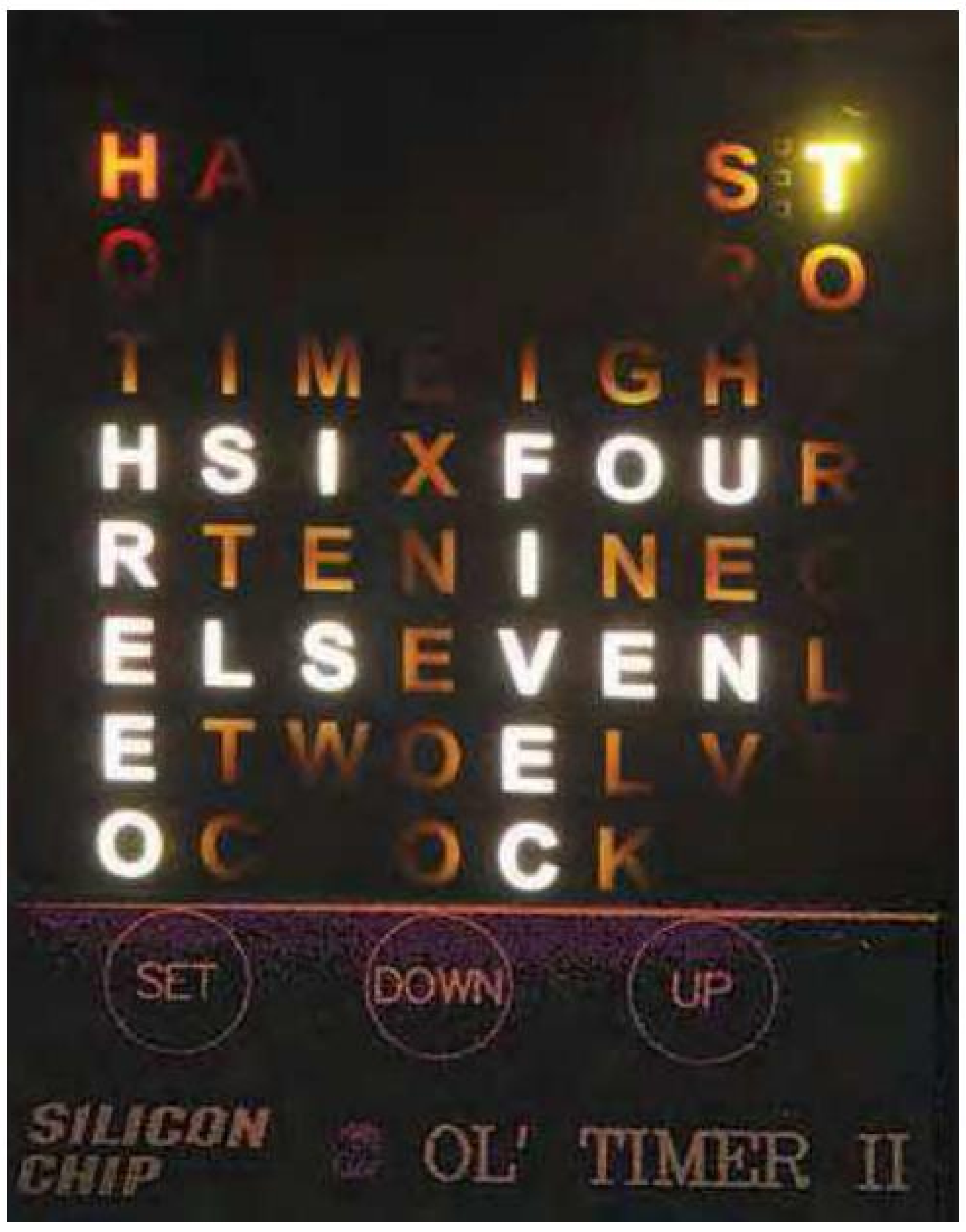
Completing assembly

Once you are happy that the clock is working correctly, fit a CR2032 battery to the holder. Check that the time is retained when the power is off. The battery should last close to its shelf life if the clock is powered most of the time.

Fit the threaded spacers to the large back panel, with screws on the matte side. Slot the side and top pieces in place. The spacers are a tight fit, so you may need to rotate them to clear the side pieces.

Note that the lefthand and righthand pieces are similar, but slightly different to fit around the USB socket or battery holder. Rest the PCB on top and use the remaining screws to secure it to the spacers and the remainder of the case.

The clock is now able to sit upright on its bottom edge.



There are nine colour pages, one each for the red, green and blue components of the hour, minute, and AM/PM colour. The displayed colour is in hexadecimal (FF here) and jumps by 15 steps at each press. For a simpler way to set the colours, use the USB terminal.

Final notes

Coin cells can be dangerous if they are ingested. Thus the clock should be kept away from small children and babies.

We suspect it would be very difficult to remove the battery from the *Ol' Timer II* without removing the back of the case, but we recommend not taking any chances with this.

If you wish to be even more cautious, you could secure the battery in place with some glue or silicone sealant.

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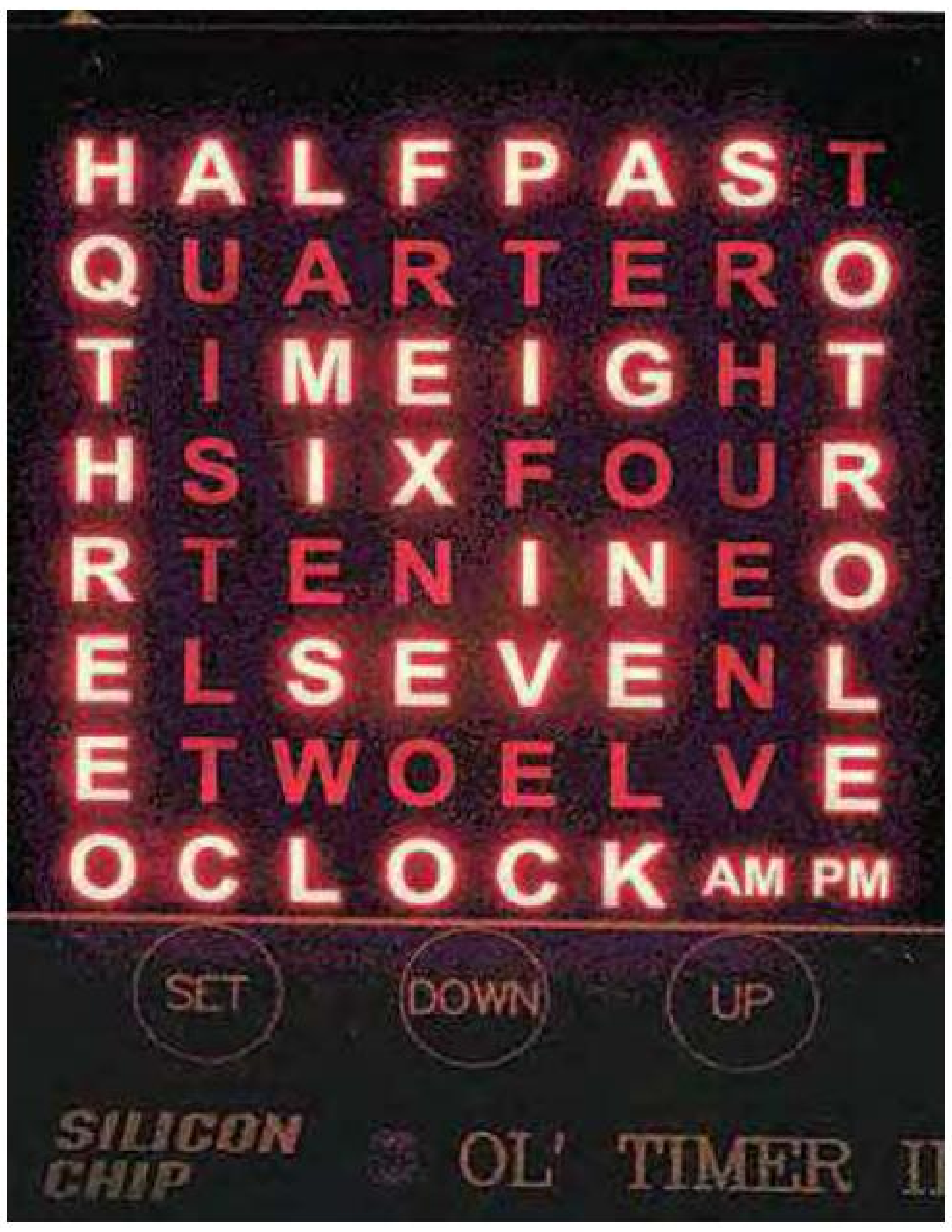


The settings are not saved by default. You should press the UP or DOWN button when this icon is visible to save the settings to Flash memory, meaning they are loaded at power-on.

by Jim Rowe

Low-cost, Wideband Digital RF Power Meter

PC (USB) &
5V DC INPUT
RF Pwr= -71.9dBm
=57.0uW At=00dB
SILICON CHIP
www.siliconchip.com.au
WIDEBAND DIGITAL RF POWER METER
DECREASE VALUE
INCREASE VALUE
SELECT ATTEN. SAVE
RF INPUT (Zin = 50Ω)

Simple to build and low in cost, this *Digital RF Power Meter* will be very useful for anyone who needs to measure radio frequency signals from 1MHz to 6GHz. By itself, it can only handle power levels up to about 3mW (5dBm), but its range can easily be extended using fixed attenuators.

While examining a Banggood RF Power Meter, it occurred to me that we could design a similar device that wouldn't cost much more to build, but would handle much higher frequency signals.

I also realised that its construction could be made easy by using other low-cost prebuilt modules that I had reviewed.

The concept quickly solidified around using an Arduino Nano module as the 'brains', together with the *Banggood RF Detector* module I reviewed in the March 2019 issue.

It offers useful capability, such as a frequency range up to above 6GHz, the ability to send the results of each measurement to your PC for data logging, and an allowance for fixed attenuators at the *Meter's* input to extend its power range. I freely admit this last idea was copied from the Banggood *RF Power Meter*...

The Meter's heart

The Analog Devices AD8313 demodulating logarithmic amplifier IC in the RF detector module forms the heart of the *Meter*. It accurately converts an RF signal into a decibel-scaled DC output voltage. It maintains accurate log conformance for signals from 1MHz to 6GHz and provides useful operation to 8GHz.

The input range is typically 60dB (referenced to 50Ω), with errors less than ±1dB up to 5.8GHz.

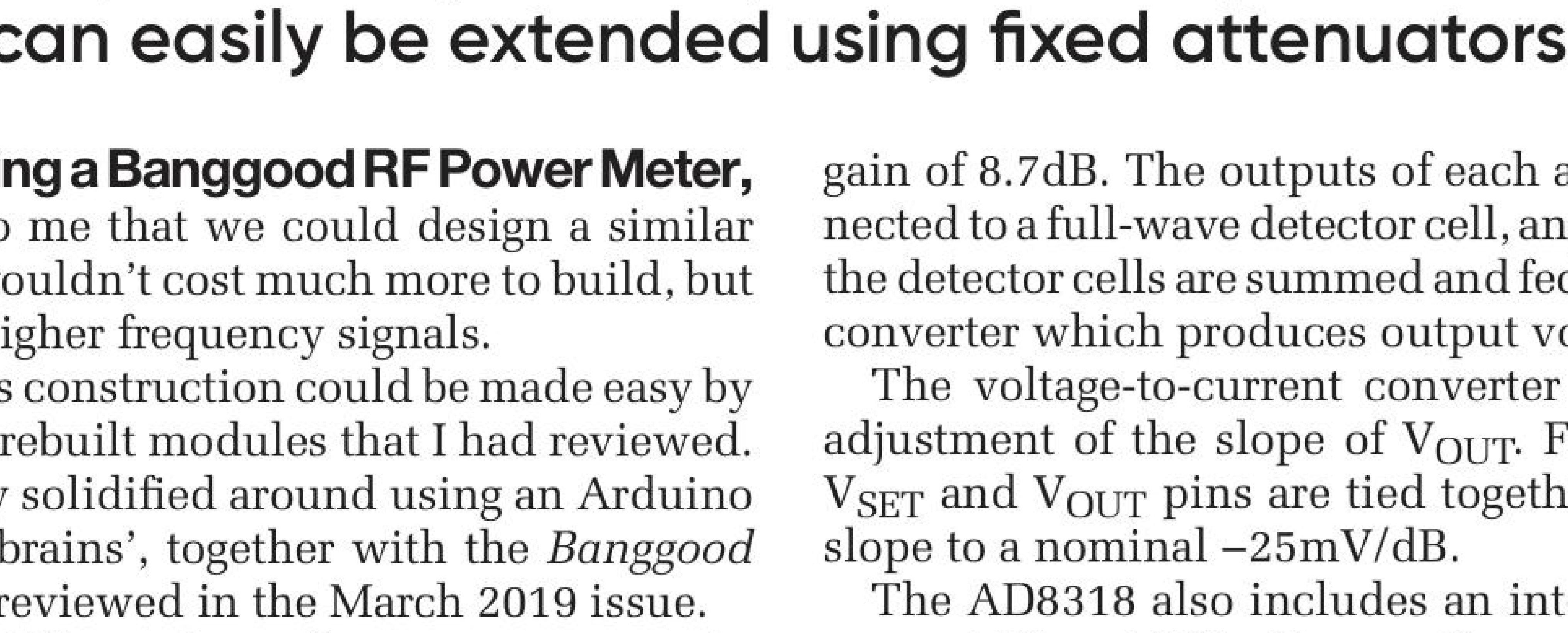

INPUT HIGH
INPUT LOW
NINE 8.7dB GAIN, 10.5GHz BANDWIDTH AMPLIFIER/LIMITER STAGES
AD8318
I ← V
VSET
I → V
NINE FULL-WAVE DETECTOR CELLS WITH OUTPUT CURRENTS ALL SUMMED
Σ
VOUT
CLPF
TEMP
TEMP SENSOR
GAIN BIAS
SLOPE

Fig.1: internal block diagram for the AD8318 log detector IC. The differential input signal passes through a string of nine amplifiers/limits and the outputs of each one go to full-wave detectors. The direct currents from each detector are summed and converted to a voltage which appears at V_{OUT}.

Fig.1 shows how the AD8318 works. It has nine cascaded amplifier/limiter stages, each with a gain of 8.7dB. The outputs of each amplifier stage are connected to a full-wave detector cell, and the output currents of the detector cells are summed and fed to a current-to-voltage converter which produces output voltage V_{OUT}.

The voltage-to-current converter at upper right allows adjustment of the slope of V_{OUT}. For example, when the V_{SET} and V_{OUT} pins are tied together, this sets the output slope to a nominal –25mV/dB.

The AD8318 also includes an internal temperature sensor and bias stabilisation on the cascaded gain stages, so that changes in ambient temperature do not unduly affect accuracy. And all of this impressive technology is squeezed into a tiny 4 × 4mm 16-lead LFCSP surface-mount package.

Fig.2 shows the measured transfer characteristic of an AD8318 at four different frequencies: 100MHz, 1GHz, 2GHz and 4GHz. It's very close to linear at –25mV/dB at all four frequencies, between 0dBm and –60dBm.

Fig.3 is the full circuit of the Banggood log detector module we are using. There's very little in it apart from the AD8318 and a 78L05 regulator, which provides the AD8318 with a regulated +5V supply. (We are actually bypassing the 78L05 in this project, as you'll learn shortly.)

The full circuit

The full circuit for our new *Digital RF Power Meter* is shown in Fig.4. The Banggood AD8318-based log detector module is at upper left, connected to the rest of the circuit via

CON2. The Arduino Nano MCU 'brain' is on the right. IC1 in the centre, an LTC2400CS8 high-resolution (24-bit) ADC (analogue-to-digital converter), is used to digitise the output voltage from the log detector module.

This ADC requires a reference voltage to set its input scaling, and this is provided by accurate 2.500V reference REF1, an LT1019ACS8.

IC1 digitises its input voltage under the control of the Arduino MCU via an SPI interface using Nano pins 1 (SCK), 30 (MISO) and 28 ($\overline{\text{SS}}$). After the MCU processes the digitised sample data, it displays the calculated RF power and voltage levels on the 16×2 LCD module via CON1. This is via an I^{2}C interface using MCU pins 8 (SDA) and 9 (SCL) – the LCD module is an I^{2}C serial type.

Three pushbutton switches (S1-S3) are connected to MCU pins 25, 23 and 21. These are used to tell the unit when you have connected one or more external RF attenuators ahead of the *Meter's* RF input, to increase its measurement range. It then adjusts its display to give correct readings.

Since the *Meter* is designed to operate from a 5V DC supply derived via the USB cable connected to the Arduino Nano, the supply for the rest of the *Meter* circuitry is taken from MCU pin 12. This goes directly to the LCD module (again via CON1). For the rest of the circuitry, it is filtered by inductor RFC1 and several bypass capacitors.

We are making a few minor modifications to the Banggood Log Detector module to simplify using it in the *RF Meter* project. The 78L05 regulator on the module needs an input of at least 7V for proper regulation, but we don't have that.

Instead, we have a well-filtered 4.75V rail after the 4.7Ω series resistor. So we are bypassing the 78L05 in the module by connecting the supply wire from CON2 directly to its output pin 1.

To make sure that the 78L05 isn't damaged by reverse current, it's a good idea to remove the 10kΩ resistor in series with the LED at the input of the 78L05. It's pretty unlikely that such a small current would damage the regulator, but the LED won't be visible once the case is on anyway, so it just wastes power if left in-circuit.

Features and Specifications

Function:
A compact, low-cost RF power and level meter with LCD screen and USB interface

Frequency range:
from 1MHz to over 6.0GHz

Input impedance:
50Ω nominal

Maximum input power level:
+5dBm (3.2mW/398mV RMS)

Minimum input power level:
–60dBm (1nW/224µV RMS)

Measurement range:
–60dBm (224µV RMS) to +33dBm (10V RMS) with recommended attenuators

Measurement linearity:
about ±1dBm, 10MHz to 1GHz, +6dBm/–4dBm, 1MHz to 4.0GHz (see measurement plots)

Measurement resolution:
approximately ±0.1%

Power supply:
5V DC at less than 120mA via USB micro-B socket

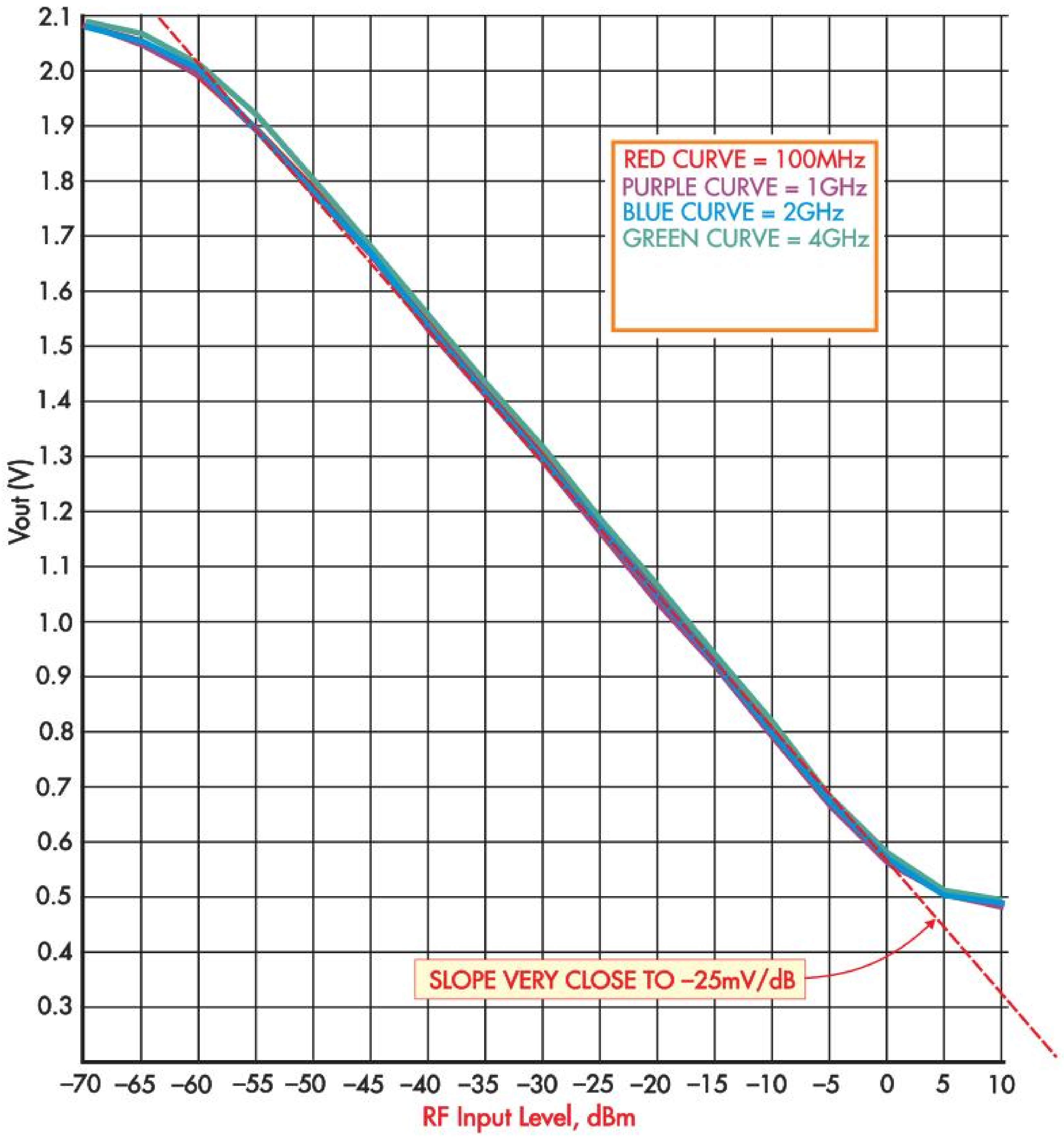


Fig.2: plot of V_{OUT} vs input signal level for the AD8318 at four different frequencies (default slope setting of –25mV/dB). As you can see, the linearity is excellent, and the frequency has minimal effect on the measured RF power level.

The only other modification needed is to fit a 1nF SMD ceramic capacitor (2012/0805-size) across the two pads just to the left of the 2-pin output connector on the log detector PCB. This provides additional filtering for the AD8318's internal feedback loop – it's shown as C_{OBP} on Fig.4.

All of these modifications should be clear from both the notes on the circuit (Fig.3) and the close-up photo of the log detector module PCB.

Pin 8 of IC1 (the LTC2400 ADC) is taken to the centre pin of JP1, a three-pin header. This allows the sampling frequency of IC1 to be set for optimum rejection of any power line frequency components in its input signal.

When the jumper shunt fitted to JP1 is in the lower position, the sampling frequency is set to reject 60Hz components

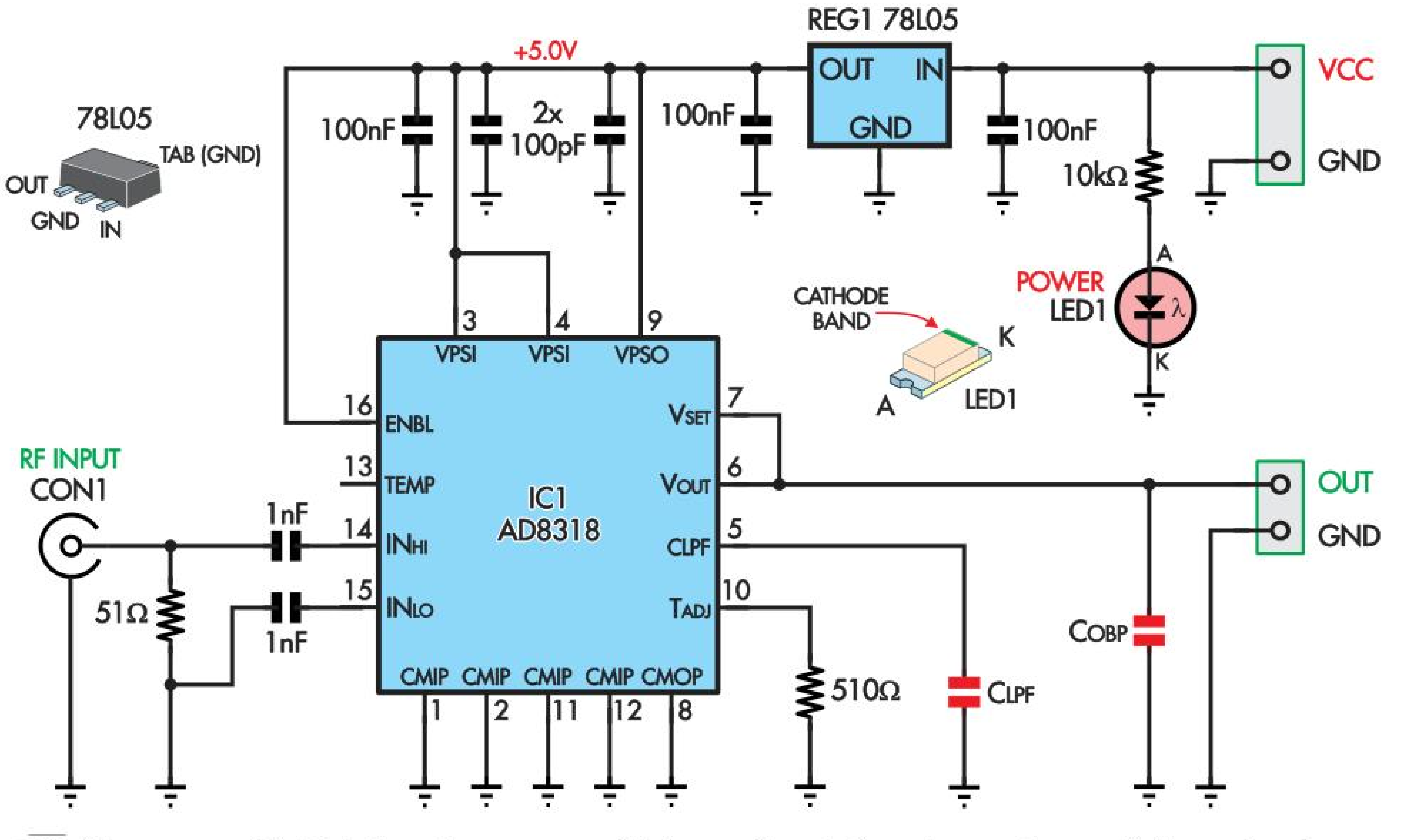
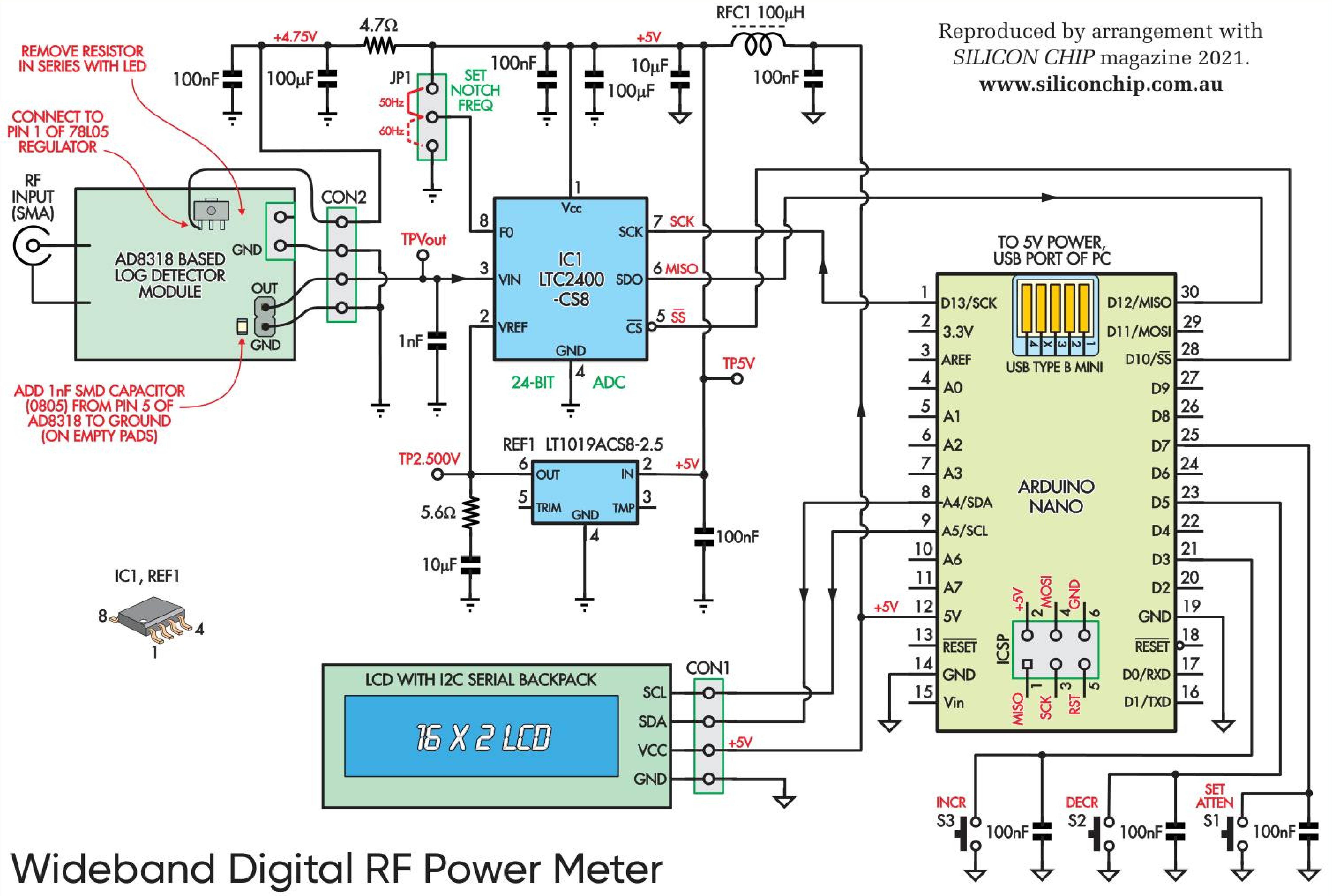


Fig.3: the circuit of the pre-assembled log detector module is very simple. The RF signal is terminated with a 51Ω resistor (52.3Ω might be better) and coupled to the inputs of IC1 via a pair of 1nF capacitors. The output from IC1 is fed to a pin header, while power is supplied via a 2-way terminal block. We're bypassing 5V regulator REG1 in this project.


REMOVE RESISTOR IN SERIES WITH LED
CONNECT TO PIN 1 OF 78L05 REGULATOR
RF INPUT (SMA)
AD8318 BASED LOG DETECTOR MODULE
GND
OUT
GND
ADD 1nF SMD CAPACITOR (0805) FROM PIN 5 OF AD8318 TO GROUND (ON EMPTY PADS)
CON2
+4.75V
4.7Ω
100nF
100µF
JP1
50Hz
60Hz
SET NOTCH FREQ
TPVout
1nF
100nF
10µF
100µF
+5V
RFC1 100µH
100nF
IC1 LTC2400 -CS8
Vcc
F0
VIN
VREF
GND
SCK
SDO
CS
SCK
MISO
SS
24-BIT ADC
TP5V
REF1 LT1019ACS8-2.5
OUT
IN
TRIM
GND
TMP
TP2.500V
5.6Ω
10µF
100nF
IC1, REF1
TO 5V POWER, USB PORT OF PC
USB TYPE B MINI
ARDUINO NANO
D13/SCK
3.3V
AREF
A0
A1
A2
A3
A4/SDA
A5/SCL
A6
A7
5V
RESET
GND
Vin
D12/MISO
D11/MOSI
D10/SS
D9
D8
D7
D6
D5
D4
D3
D2
GND
RESET
D0/RXD
D1/TXD
ICSP
+5V
MOSI
GND
MISO
SCK
RST
LCD WITH I2C SERIAL BACKPACK
16 X 2 LCD
CON1
SCL
SDA
VCC
GND
INCR S3
DECR S2
SET ATTEN S1
100nF

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Wideband Digital RF Power Meter

Fig.4: thanks to the use of three prebuilt modules, the circuit of the *RF Power Meter* is not too complicated. The Arduino Nano uses 24-bit analogue-to-digital converter IC1 to read the output of the log detector with high precision. 2.5V reference REF1 ensures that IC1 measures that signal with reference to a very stable voltage. The whole circuit is powered from the 5V pin of the Nano, which gets its power from a USB charger or computer.

(as you'd need in the US), but if the jumper shunt is fitted in the upper position, the sampling frequency is set to reject 50Hz components. So the latter position is the best one for use in Australia, New Zealand or the UK.

What the firmware does

The firmware sketch for the *Digital RF Power Meter* is called **RF_Power_Meter_sketch.ino** and is available for free downloading from the August 2021 page of the *PE* website. When uploaded to the Arduino Nano's ATmega328P micro, it does several things.

Its main task is to direct IC1, the ADC, to take a sequence of 10 measurements of the output voltage V_{OUT} from the log detector module. It then averages each group of measurements and calculates from that the corresponding RF power level in dBm and the equivalent voltage level in millivolts or microvolts.

These figures are then sent to the LCD module for display, and are also sent out via the *Meter's* USB data line for display and possible logging on a computer.

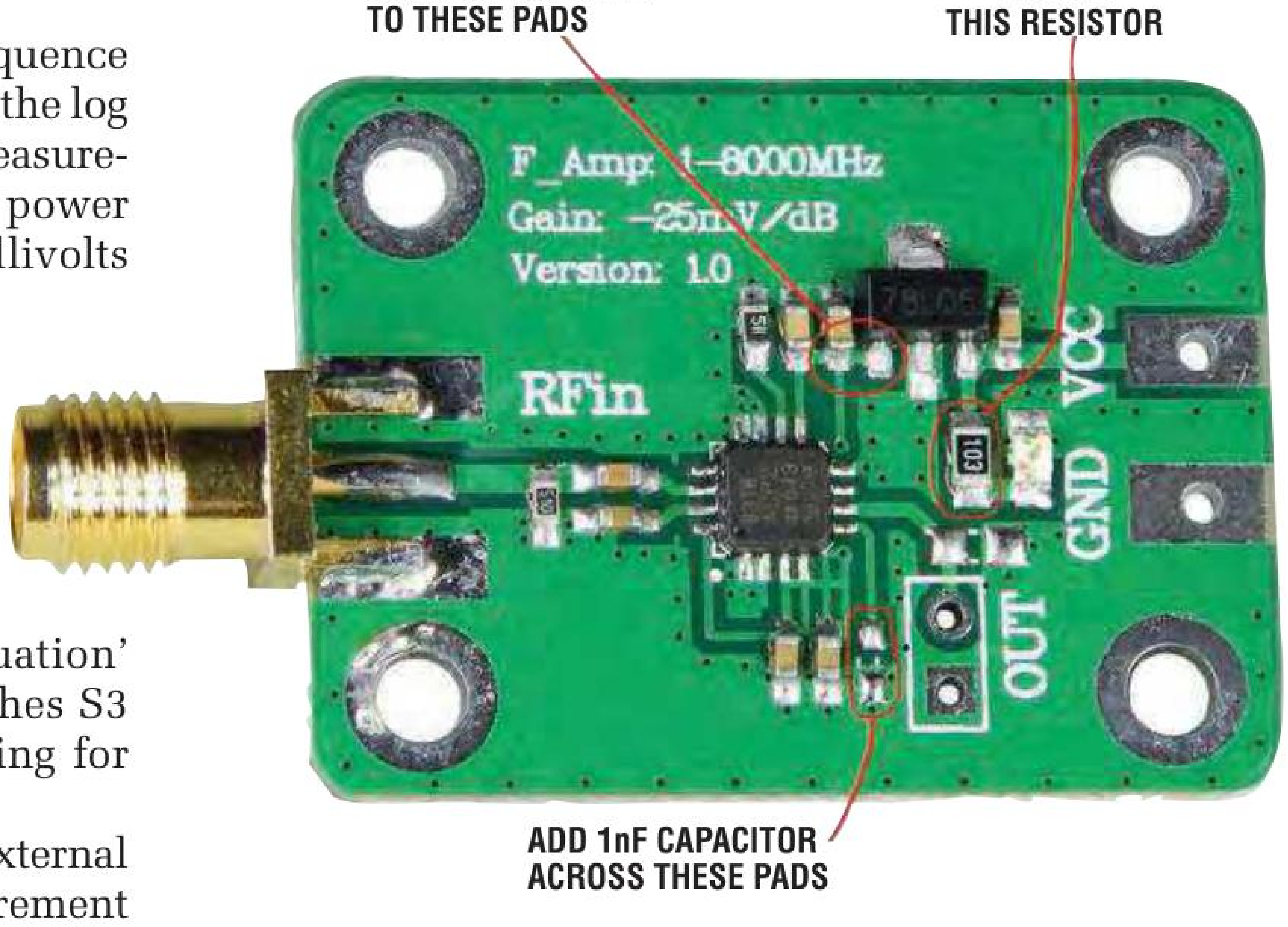
The firmware's other main task is to check between measurement cycles for any presses of the Select Attenuation pushbutton switch, S1. If S1 has been pressed, it then swings into 'change attenuation' setting mode and it monitors any presses of switches S3 ('Increase') or S2 ('Decrease') and adjusts its setting for the external attenuation in steps of 1dB.

Then, when S1 is pressed again, it saves the new external attenuation figures and returns to its normal measurement mode. The attenuation value is set to zero each time the unit is powered up.

Construction

The complete *Digital RF Power Meter* is housed in a diecast aluminium box measuring 119 × 93.5 × 56.5mm. Pushbutton switches S1-S3 and the LCD module all mount on or behind the box lid/front panel.

All of the other modules and components are mounted on a double-sided PCB measuring 109 × 83mm, coded 04106201 and avaiable from the *PE PCB Service*. This also mounts behind the box lid/front panel, via four pairs of spacers.


F_Amp: 1-8000MHz
Gain: -25mV/dB
Version: 1.0
RFin
VCC
GND
OUT
78L05
103

CONNECT +5V WIRE TO THESE PADS

REMOVE THIS RESISTOR

ADD 1nF CAPACITOR ACROSS THESE PADS

A few minor modifications need to be made to the Banggood module before fitting it to the PCB.

Begin construction by first fitting the passive SMD components to the main PCB, using the overlay diagram of Fig.5 and the matching photo as a guide.

Then fit RFC1, which is larger and will probably need a hotter iron. It's best to smear a thin layer of flux paste on its pads before soldering it in place. After this, install IC1 and REF1, which are both in SOIC-8 SMD packages.

Next, mount 4-pin SIL headers CON1 and CON2, along with the 3-pin header for JP1. Then you can fit the four PCB terminal pins, which all push through their matching holes in the main PCB and are soldered to the pads underneath. Two are to the left of RFC1 (TP$_{GND}$ and TP$_{5V}$), while a third pin (TP$_{2.5V}$) is to the right of REF1 and the fourth (TP V$_{OUT}$) is to the right of CON2.

You should then be able to fit the Arduino Nano module to the PCB, with its 30 pins passing down through the matching holes and soldered to the pads underneath.

The final step in assembling the main PCB is to fit the AD8318 log detector module. It mounts on the top of the main PCB using four 10mm-long M3 machine screws, with an M3 nut used on each screw as a spacer, and then further M3 nuts underneath to complete the job.

Once it has been secured, plug a 4-pin SIL socket into header CON2 and solder four short lengths of light-duty hookup wire to its pins, then to the matching points on the module using Fig.5 as a guide.

By the way, although the log detector module shown in the photos and diagrams is fitted with a small two-way terminal block for power and a two-pin header for V$_{OUT}$, the module as supplied may not have these.

Neither connector is required in this application, as you can simply solder the wires to the pads on the PCB.

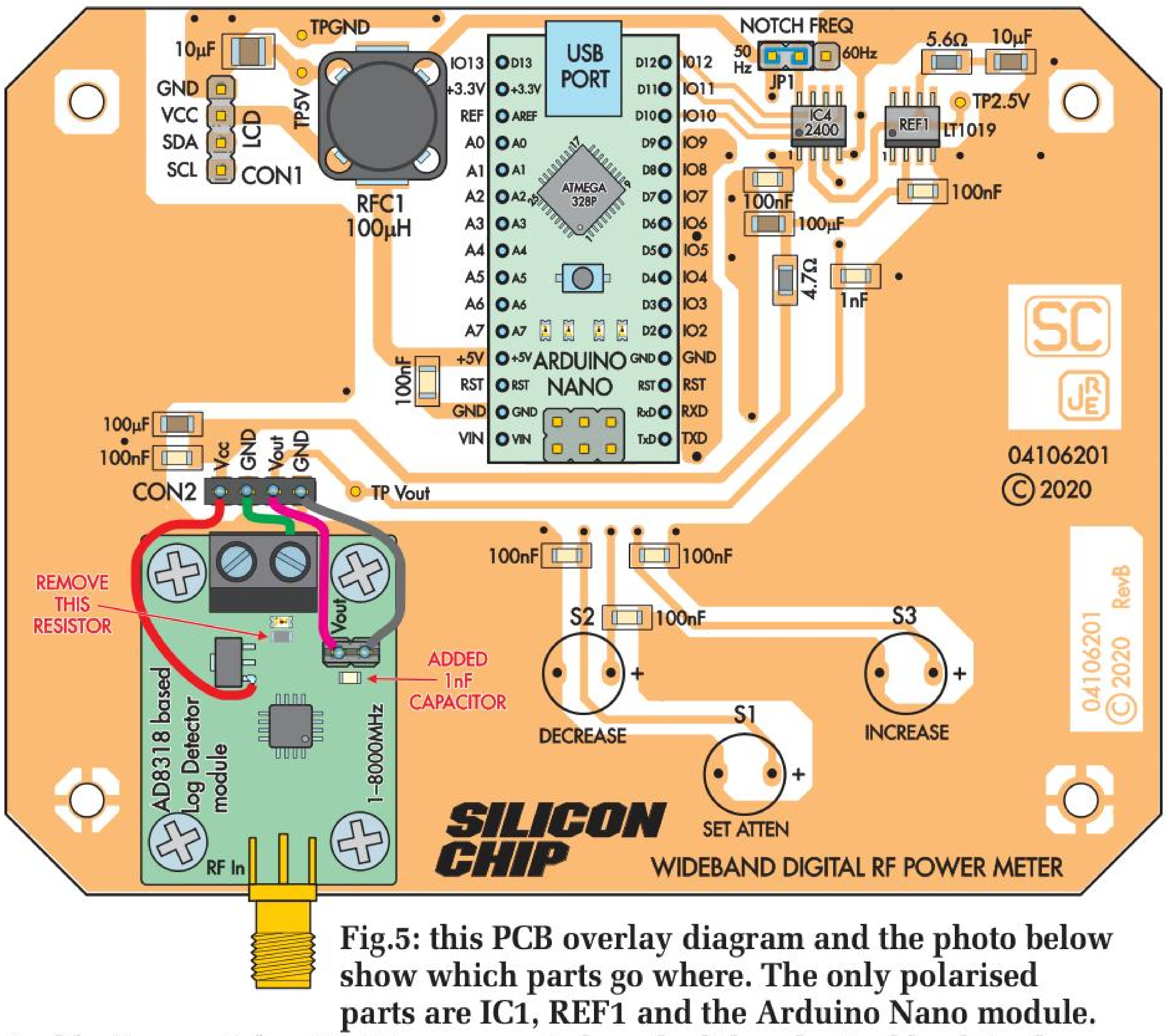
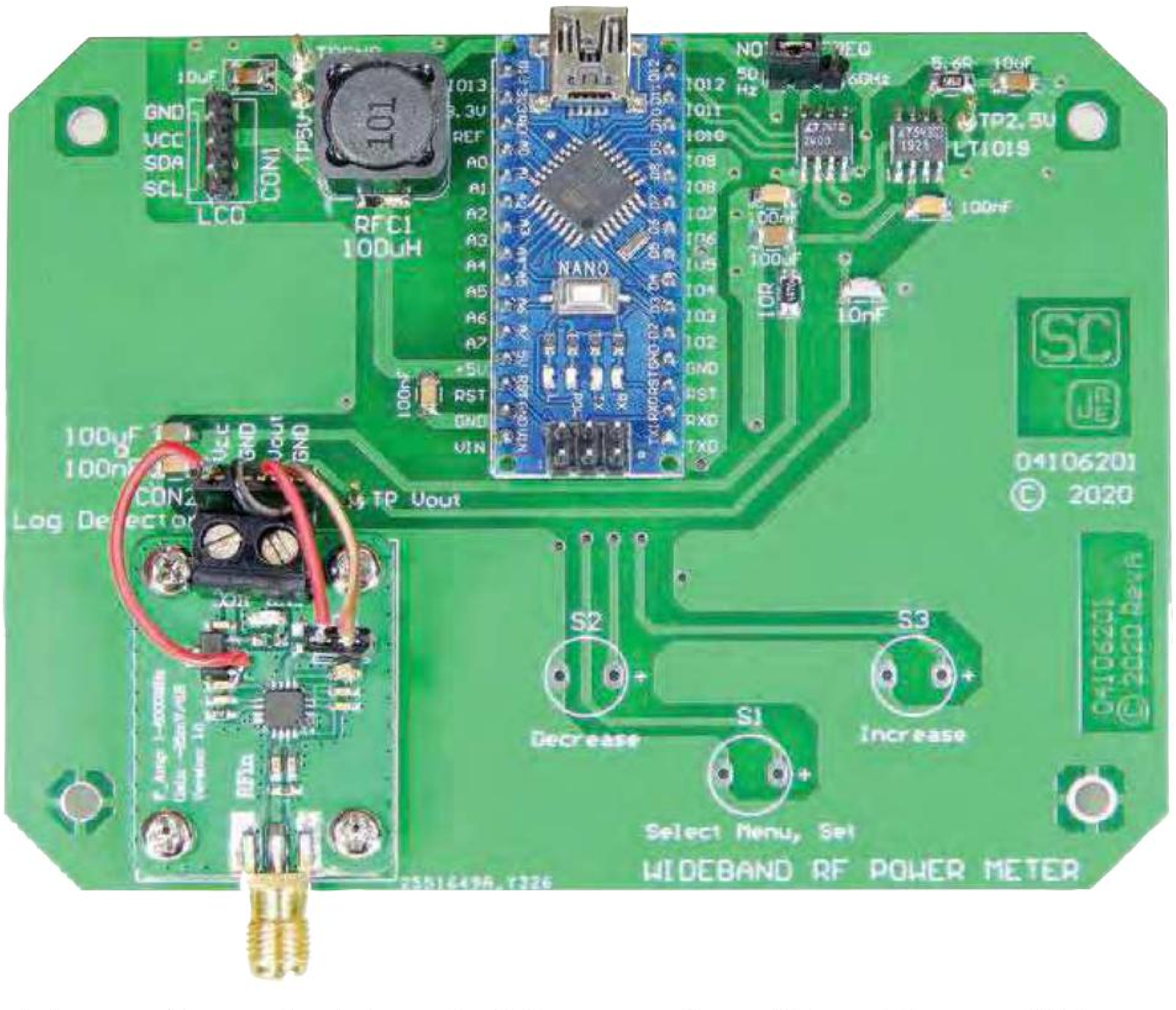

10µF
TPGND
GND
VCC
SDA
SCL
LCD
CON1
TP5V
RFC1
100µH
USB PORT
ATMEGA 328P
ARDUINO NANO
NOTCH FREQ
50 Hz
60Hz
JP1
IC4 2400
REF1
LT1019
5.6Ω
10µF
TP2.5V
100nF
100µF
4.7Ω
1nF
100nF
CON2
Vcc
GND
Vout
GND
TP Vout
REMOVE THIS RESISTOR
ADDED 1nF CAPACITOR
AD8318 based Log Detector module
1–8000MHz
RF In
S2
S3
S1
DECREASE
INCREASE
SET ATTEN
SC
04106201
© 2020
04106201 RevB © 2020
SILICON CHIP
WIDEBAND DIGITAL RF POWER METER

Fig.5: this PCB overlay diagram and the photo below show which parts go where. The only polarised parts are IC1, REF1 and the Arduino Nano module. Pushbutton switches S1-S3 are mounted on the lid and wired back to the board using flying leads, while the header on the LCD screen (also mounted on the lid) is soldered directly to the pins of CON1 as the last step in the assembly.


Log Detector
Decrease
Select Menu, Set
Increase
WIDEBAND RF POWER METER

Case preparation

There are only two holes to be cut in the box proper: an 11mm-diameter round hole in the front, and a 9 × 11mm rectangular hole in the rear. The location of each of these holes is shown in Fig.6.

There are 12 holes to be cut in the box lid, which becomes the *Meter's* front panel. The locations and sizes of these holes are shown in Fig.7. There are three 12.5mm holes for the three pushbutton switches and a 65 × 15mm rectangular hole for the LCD 'window'. The remaining small holes are for mounting the LCD module and the main PCB.

After you have made and deburred all the holes in the lid/front panel, it's a good idea to attach a dress front panel to the front for a professional appearance.

We have prepared full-size artwork for this, which can be downloaded from the August 2021 page of the *PE* website as a PDF file.

You can print this out in colour and then hot-laminate it in an A5 laminating pouch. After this you can cut it to size, punch four 3mm holes (one in each corner) and then attach it to the front of the lid using either thin double-sided cellulose tape or contact adhesive. Once it is securely attached, cut out the remaining holes using a sharp hobby knife.

The next step is to attach an 80 × 25mm rectangle of thin clear plastic (say, 0.4mm thick) behind the LCD window cutout, to protect the screen from dirt and damage. This can be attached using standard cellulose tape, taking care not to cover the LCD module mounting holes.

The lid assembly can now be finished. Mount the LCD module behind the window using four 16mm-long M2.5 countersunk screws, four 9mm-long untapped spacers, three or four nylon washers and then four M2.5 nuts, as shown in Fig.8 and the photos.

Then you can mount the three pushbutton switches using the supplied plastic nuts, and finally attach a 25mm-long M3 tapped spacer near each corner using a 6mm-long M3 machine screw. The rear of your lid/front panel should now look like the photo.

Next, cut six 25mm lengths of single-core hookup wire (three red and three black) and strip off about 4-5mm of the insulation at both ends of each. Then solder one end of each

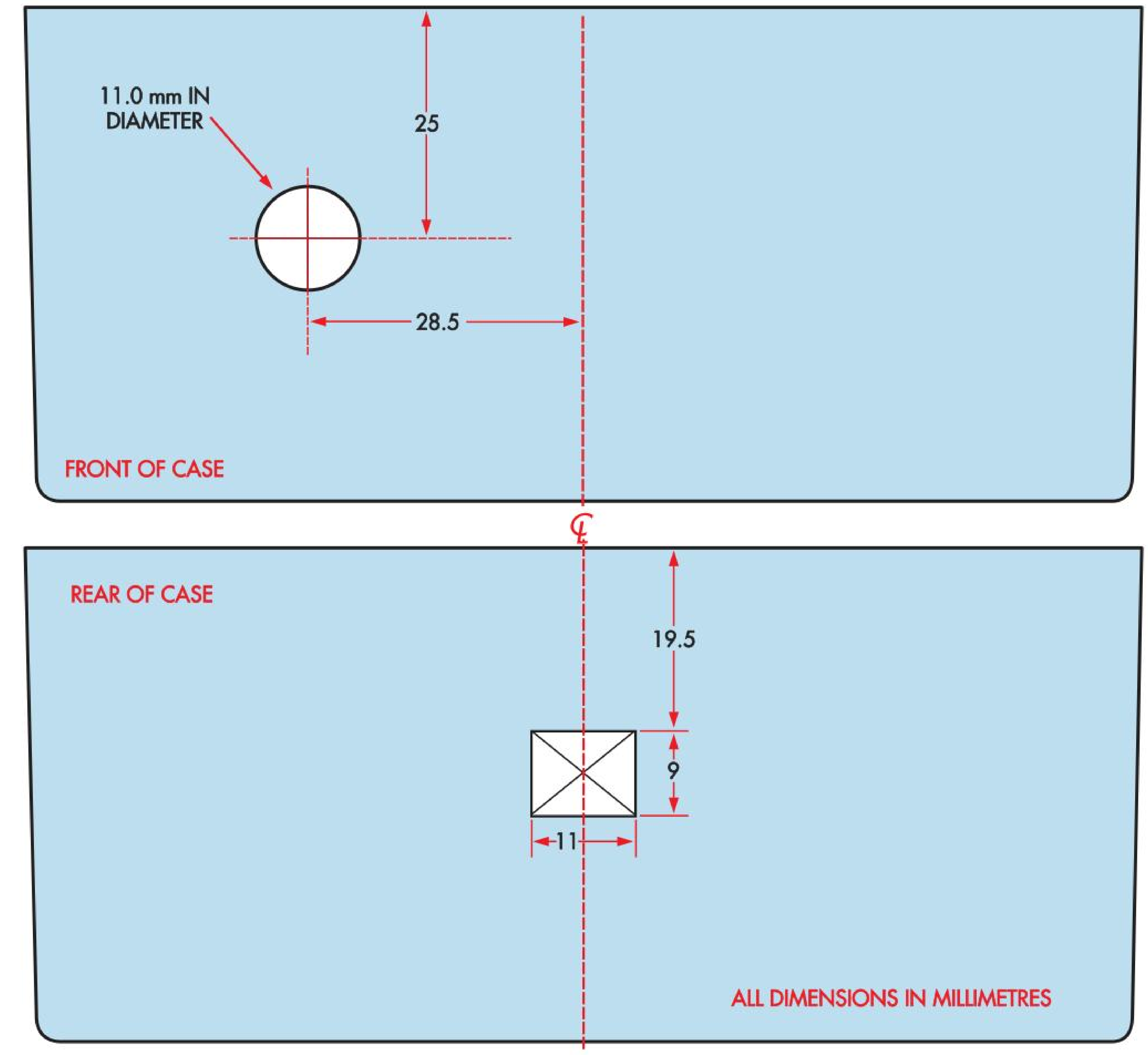
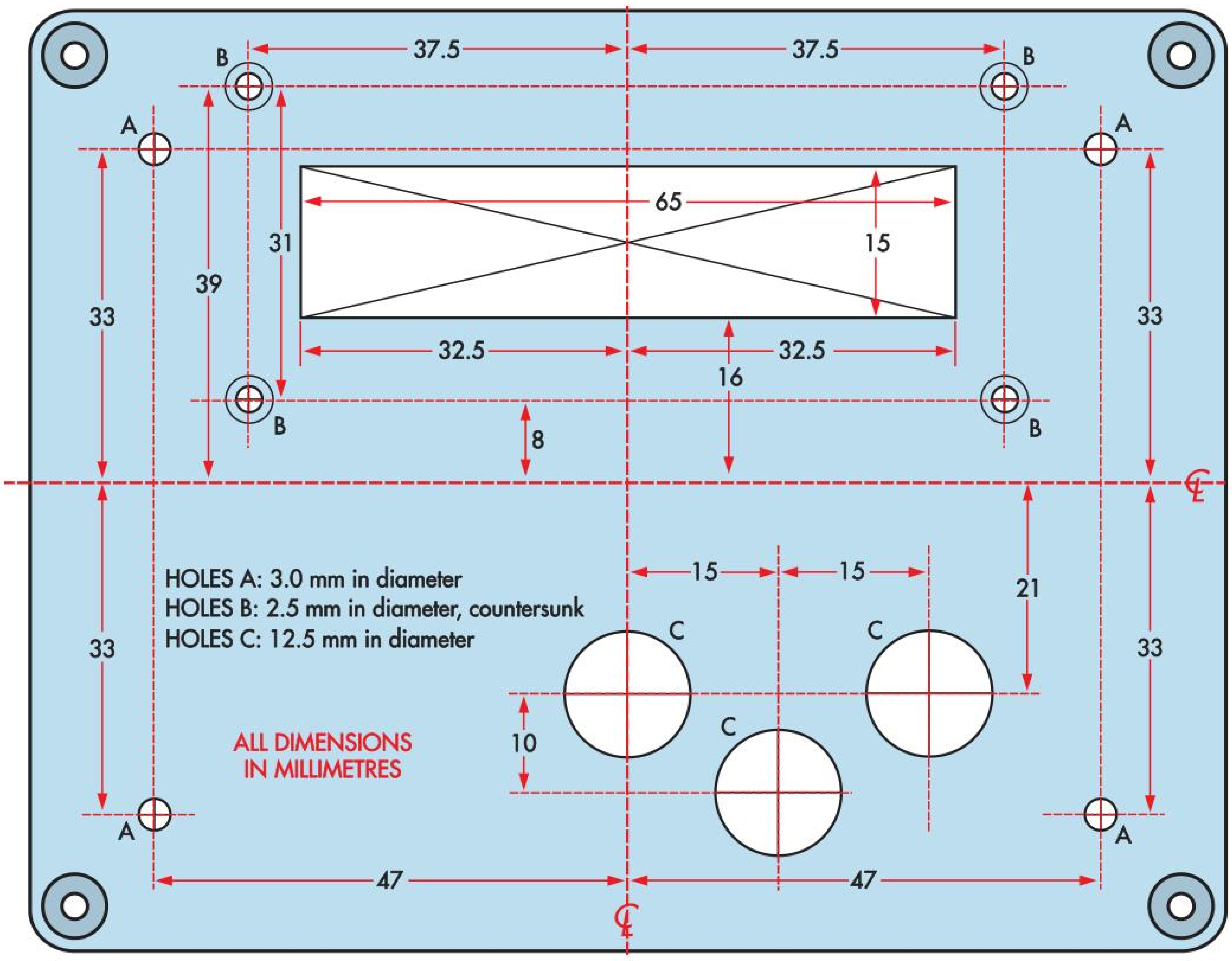


Fig.6: only two holes need to be made in the main part of the case, with the locations and sizes shown here. The round hole is for the SMA RF input connector, while the rectangular cutout allows a USB micro-B plug to be inserted into the socket on the Nano board



HOLES A: 3.0 mm in diameter
HOLES B: 2.5 mm in diameter, countersunk
HOLES C: 12.5 mm in diameter

Fig.7: most of the holes that need to be made are actually in the case lid, including a large rectangular cutout for the LCD screen. This is best made by drilling a series of small (say 2mm) holes around the inside of the perimeter, knocking the inside part out, then filing the edges to shape. You can use a similar technique for the USB socket hole in the base.

red and black pair of wires to the connection lugs at the rear of each pushbutton switch. These are to connect the switches to their matching pads on the main PCB.

Photos of the front (above) and rear (below) of the assembled project showing the holes required, These photos match Fig.6, left.

After plugging a four-pin SIL socket into CON1, attach the main PCB using four 12mm M3 screws through each corner of the PCB, with a 6mm-long untapped spacer between the PCB and each 25mm-long tapped spacer – see Fig.8. The only trick is making sure that the wires from each pushbutton pass through their matching holes in the main PCB, although you can adjust them later if necessary.

Once all the switch wires are through their corresponding PCB pads, upend the assembly and solder the wires to those pads.

The final step is to solder the four pins of the SIL header on the LCD module to the corresponding pins at the top of the SIL socket you fitted to CON1.

You may need to slightly bend the LCD header pins using a pair of needle-nose pliers, so that they are close to the pins of the SIL socket, allowing them to be soldered together. If this proves a little tricky, it can help to temporarily remove the nearby tapped spacers, which can be replaced easily once the connections have been made.

Don't fit this assembly into the box just yet, since it's a good idea to check a few key voltages at this stage. It may also be necessary to adjust the contrast of the LCD to get the clearest display once the *Meter* firmware has been uploaded.

Testing and setup

First, connect the *Meter* up to a USB 5V power supply using a mini-B cable. As soon as power is applied, the LCD's backlight should illuminate. Get out your DMM and check a few voltages relative to the TP_{GND} pin at the left rear of the main PCB. You should measure close to 5V on the adjacent TP_{5V} pin, around 4.75V on the V_{CC} pin of the socket plugged into CON2, and very close to 2.5V at $TP_{2.5V}$.

If you get all of these readings, remove the power and download the *Meter's* Arduino sketch from the August 2021 page of the *PE* website.

You will need the Arduino IDE (Integrated Development Environment) to compile and upload the sketch. If you don't have it already installed, it's a free download from **www.arduino.cc/en/Main/Software**

Our sketch, **RF_Power_Meter_sketch.ino**, uses libraries: SPI.h, Wire.h and LiquidCrystal_I2C.h. The first two come as standard with the Arduino IDE, but you'll probably have to install the last one via the Library Manager or download it from github: **http://bit.ly/pe-aug21-rf**

Once ready, plug the *Meter's* USB cable into a free port of your PC. If you are running Windows 10, go into Settings -> Bluetooth & Other Devices and then go down to Other devices. You should find an entry like USB-SERIAL CH340 (COMxx), where the digits after 'COM' indicate the virtual COM port that Windows has assigned the *Meter's* Nano – or strictly, its CH340 USB-serial interface chip.

Next, start up the Arduino IDE, and go into the Tools menu. Then click on Board, which will produce a list of possible Arduino modules; select Arduino Nano from that list. Then click on Processor and select 'ATmega328P (old Bootloader)', since this is the appropriate one to communicate with the *Meter's* Nano MCU via its CH340 serial interface.

After this, click on Port, which should give a listing of any virtual COM ports that the IDE has found available. Select the COM port address that corresponds to the *Meter*.

If you haven't already loaded the LiquidCrystal_I^2C library via the Library Manager, do so now. If you downloaded the ZIP file instead, add it via the 'Add .ZIP Library' option near the top of the Sketch -> Included Library list.

Now open the downloaded sketch file and click Sketch -> Verify/Compile, After 20 or 30 seconds, you should get the message 'Done compiling' in the box near the bottom of the IDE window, plus some statistics regarding the compilation.

If all has gone well, the final step is to go into the Sketch menu again and click on Upload. When this is completed, the *Meter* should spring into life. The LCD should first display the initial greeting:

```
Silicon Chip
RF Power Meter
```

After a few seconds, it should begin displaying the results of its RF input sampling and calculations. With nothing connected to the *Meter's* RF input, you should get a display like this:

```
RF Pwr= –68.5dBm
=83.2uV At=00dB
```

If the display on the LCD is not clear and well defined – perhaps just two lines of blocks – that indicates that the contrast trimpot on the back of the LCD module needs to be adjusted. Rotate the trimpot in one direction or the other using a small screwdriver. The trimpot is just above RFC1 and the TP_{5V} and TPGND terminal pins.

The last thing to test before fitting the *Meter* assembly into its box is to make sure it is sending the test readings back to the PC.

To do this, go to the Arduino IDE and open the Tools menu. Click on Serial Monitor and it will open up another window. This should show the *Meter's* virtual COM port address at the top, and at the top of the centre area you should see:

```
Silicon Chip Digital RF Power Meter
```

Then, after a few seconds, you should see the results of the first reading on a single line:

```
RF Pwr= -68.6dBm = 82.6uV At=00dB
```

Further readings will appear every few seconds. If you don't see this display in the Serial Monitor window, or if all you see is a string of weird graphic symbols, check at the bottom right of the window to make sure that the serial data rate is set to 115,200 baud (bits per second). This is the data rate at which the *Meter's* Arduino Nano sends the reading data.

If you click on the 'Show timestamp' checkbox at bottom left of the same window, a timestamp will be added to the start of each line of readings to allow data logging.

If you have access to the equipment necessary to fine-tune the *Meter's* calibration, as described at the start of the section below, you may wish to do that now.

Otherwise, you can accept the default calibration we have built into the firmware. In that case, unplug the USB cable and lower the *Meter* assembly into the box, securing it with the four supplied mounting screws. Your *Digital RF Power Meter* is now ready for use.

Parts list
Wideband Digital RF Power Meter

1 diecast aluminium box, 119 x 93.5 x 56.5mm [Jaycar HB5064 or similar]
1 double-sided PCB coded 04106201, 109 x 83.5mm, available from the PE PCB Service
1 Arduino Nano or compatible module
1 1-8000MHz AD8318-based RF Logarithmic Detector module [eBay, AliExpress, Banggood]
1 16x2 LCD module with blue LED backlight, HD44780 or compatible controller and I^2C serial interface
3 panel-mounting SPST pushbutton switches (S1-S3) [Jaycar SP0700 or similar]
1 100µH RF choke, SMD 12 x 12 x 8mm [Jaycar LF1402 or similar]
4 25mm-long M3 tapped spacers
4 9mm-long untapped spacers
4 6mm-long untapped spacers
4 M3 x 12mm panhead machine screws
4 M3 x 10mm panhead machine screws
4 M3 x 6mm panhead machine screws
8 M3 hex nuts
4 M2.5 x 16mm countersunk machine screws
4 M2.5 hex nuts
4 nylon flat washers, 3mm inner diameter
2 4-pin SIL headers, 2.54mm pitch
1 3-pin SIL header, 2.54mm pitch
2 4-pin SIL header sockets, 2.54mm pitch
1 2-pin SIL header socket, 2.54mm pitch
1 jumper shunt/shorting block
2 100mm lengths of light-duty hookup wire (red and black)

Semiconductors
1 LTC2400-CS8 24-bit ADC, SOIC-8 (IC1) [Digi-Key LTC2400CS8#PBF-ND]
1 LT1019ACS8-2.5 voltage reference (REF1) [Digi-Key LT1019ACS8-2.5#TRPBFCT-ND]

Capacitors
2 100µF 10V X5R SMD ceramic, 3216/1206-size
2 10µF 16V X7R SMD ceramic, 3216/1206-size
7 100nF 50V X7R SMD ceramic, 3216/1206-size
2 1nF 50V C0G or NP0 SMD ceramic, 2012/0805-size

Resistors (all SMD 1%, 3216/1206 size)
1 5.6Ω (code 5R6 or 5R60)   1 4.7Ω (code 4R7 or 4R70)

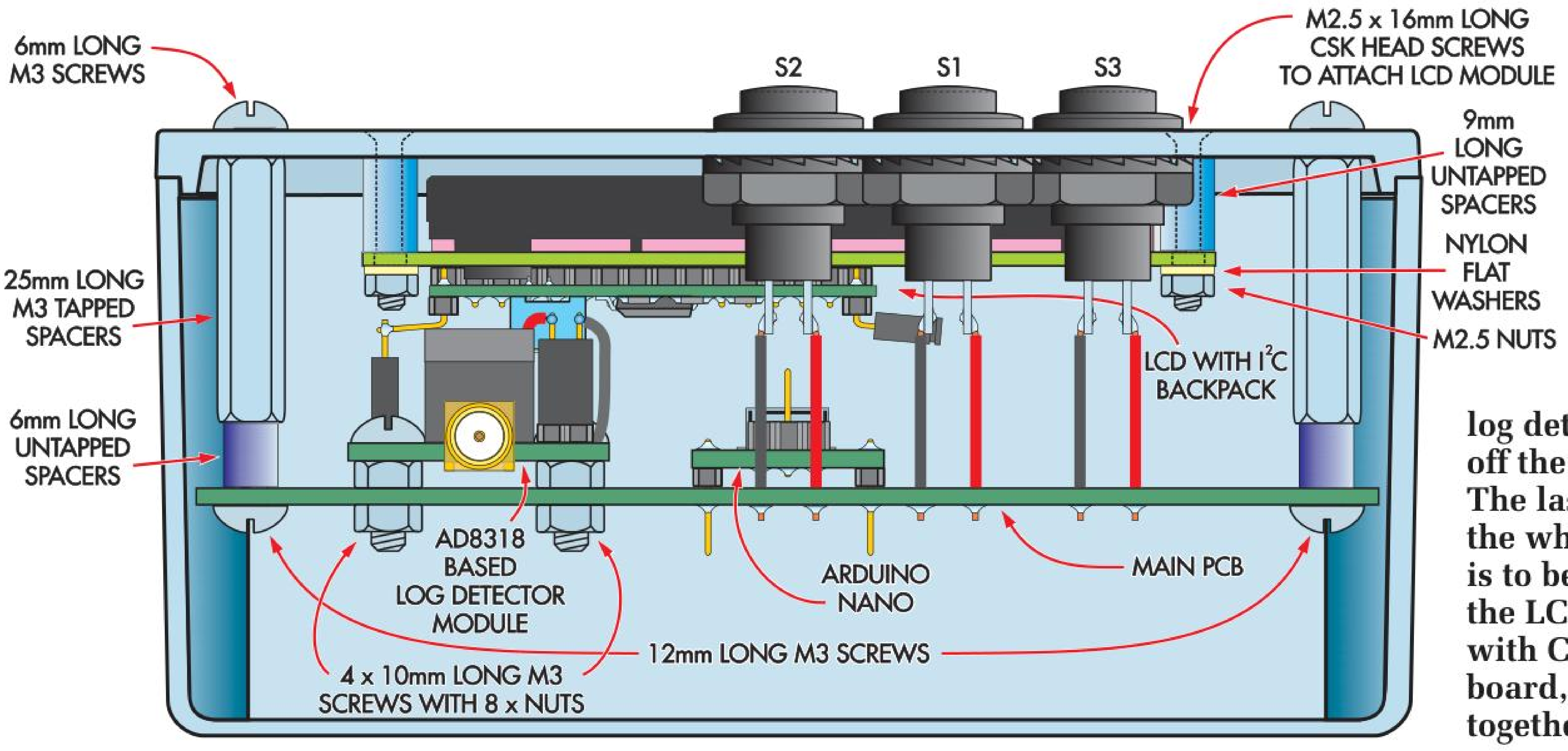

6mm LONG M3 SCREWS
S2
S1
S3
M2.5 x 16mm LONG CSK HEAD SCREWS TO ATTACH LCD MODULE
9mm LONG UNTAPPED SPACERS
NYLON FLAT WASHERS
M2.5 NUTS
25mm LONG M3 TAPPED SPACERS
LCD WITH I²C BACKPACK
6mm LONG UNTAPPED SPACERS
AD8318 BASED LOG DETECTOR MODULE
ARDUINO NANO
MAIN PCB
12mm LONG M3 SCREWS
4 x 10mm LONG M3 SCREWS WITH 8 x NUTS

Fig.8: this side profile view shows how it all goes together and fits into the case. If you don't have untapped 6mm spacers, you could use tapped 6.3mm spacers instead. Note how the log detector module is spaced off the main PCB using nuts. The last step before dropping the whole thing into the case is to bend the 4-pin header on the LCD over to make contact with CON4 on the main board, then solder the pins together.

Calibration

To fine-tune the *Digital RF Power Meter's* calibration, you'll need a DMM able to measure DC voltages up to 2.5V with high accuracy, and a UHF signal generator which can be set to provide CW signals at 1GHz (1000MHz) with an accurate amplitude of between +5dBm and –65dBm.

The first step is to remove the *Meter* assembly from its box (if you've already finished the assembly) and apply 5V power via the USB cable. After allowing a few minutes for it to stabilise, use the DMM to measure the reference voltage at $TP_{2.5V}$, up near the right rear corner of the main PCB, relative to the TP_{GND} pin.

This should be very close to 2.5000V, but whatever the reading you get, record it carefully as V_{REF}.

Next, transfer the positive test lead of the DMM to monitor the voltage at the TP V_{OUT} terminal pin, just to the right of CON2 at the rear of the log detector module. Then connect the input of the *Power Meter* to the output of the signal generator via a short length (say 150mm) of SMA-SMA cable. The short length is to minimise cable losses.

Set the generator to provide a CW (continuous wave, ie, unmodulated) signal at 1.000GHz, with an initial level of +5dBm (1.78V RMS).

The DMM should show the log detector's V_{OUT} voltage to be around 0.5V. Record the actual value of this reading, this time with the label 'Vo5dBm'.

Next, reduce the generator output level to 0dBm (224mV RMS), and again record the DMM reading (it should be around 0.56V) with the label 'Vo0dBm'.

Repeat this exercise with the generator set to –55dBm (398μV), which should give a reading of around 1.9V, and –65dBm (126μV), which should give a reading of around 2.1V. These figures should be recorded as 'Von55dBm' and Von65dBm' respectively.

Now remove the DMM test leads and go back to the Arduino IDE, which presumably still has the *Digital RF Power Meter* sketch open. Scroll down about 50 or so lines from the top, where you'll find three lines reading:

```
byte S1 = 0;
byte S2 = 0;
byte S3 = 0;
```

Then you'll see a blank line, followed by a line reading:

```
const float Von65dBm = 2.0451;
```

In place of that figure of 2.0451, type in the reading you recorded for Von65dBm. Similarly, replace the values on the next four lines with the other readings that you noted earlier. Make sure that, in replacing these figures, you don't remove the semicolons after each one. Otherwise, the sketch won't compile.

Save the modified sketch file and recompile it by going to the Sketch menu and clicking on Verify/Compile. Then if it compiles correctly as before, click on Sketch→Upload to load the revised firmware to Flash memory on the *Power Meter's* Nano.

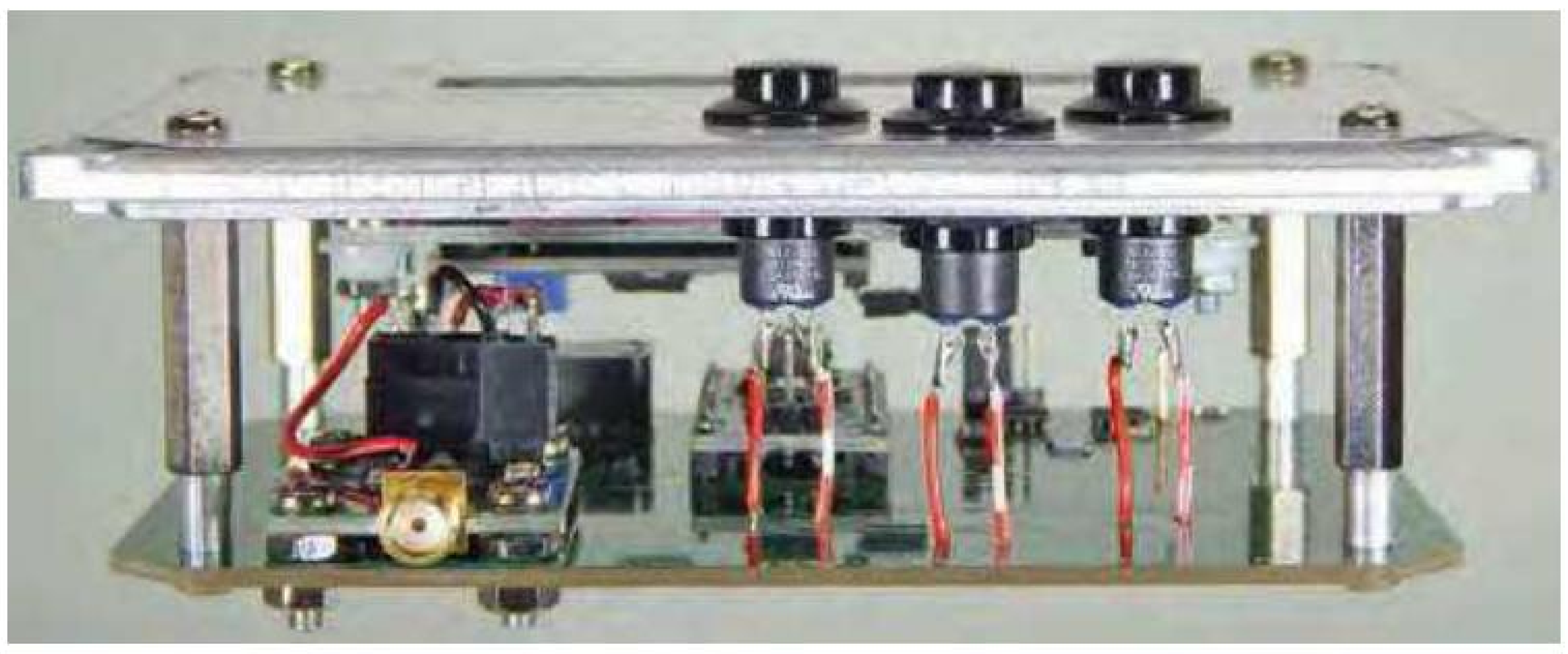
Your *Power Meter* should now be calibrated. Just to verify that this has been achieved, you can set the signal generator output to say –40dBm (2.24mV RMS), whereupon the *Meter* should give a reading very close to this figure; within ±1dBm. The calibration is then complete. You can remove the power from the *Meter* assembly and reinstall it in its box, so it's ready for use.

Typical response plot

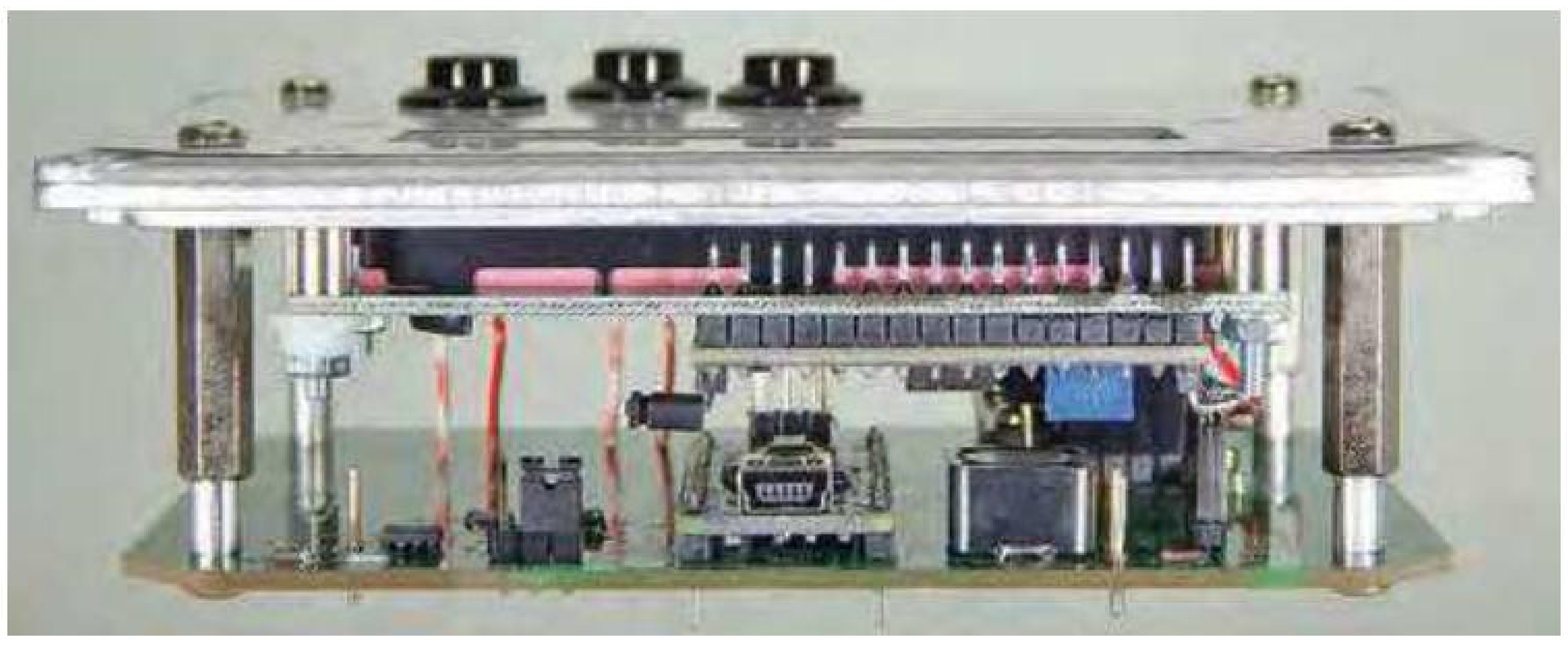
After calibrating the prototype *Digital RF Power Meter* shown in the photos, we measured its response over a range of signal levels and between 1MHz and 4.0GHz (the upper limit of the Gratten GA1484B signal generator).

The results are shown in Fig.9. This shows that the *Meter* response at most signal levels is within ±2dB up to 1.0GHz, rising to a peak of around +6dB at 2.5GHz, before falling away again.

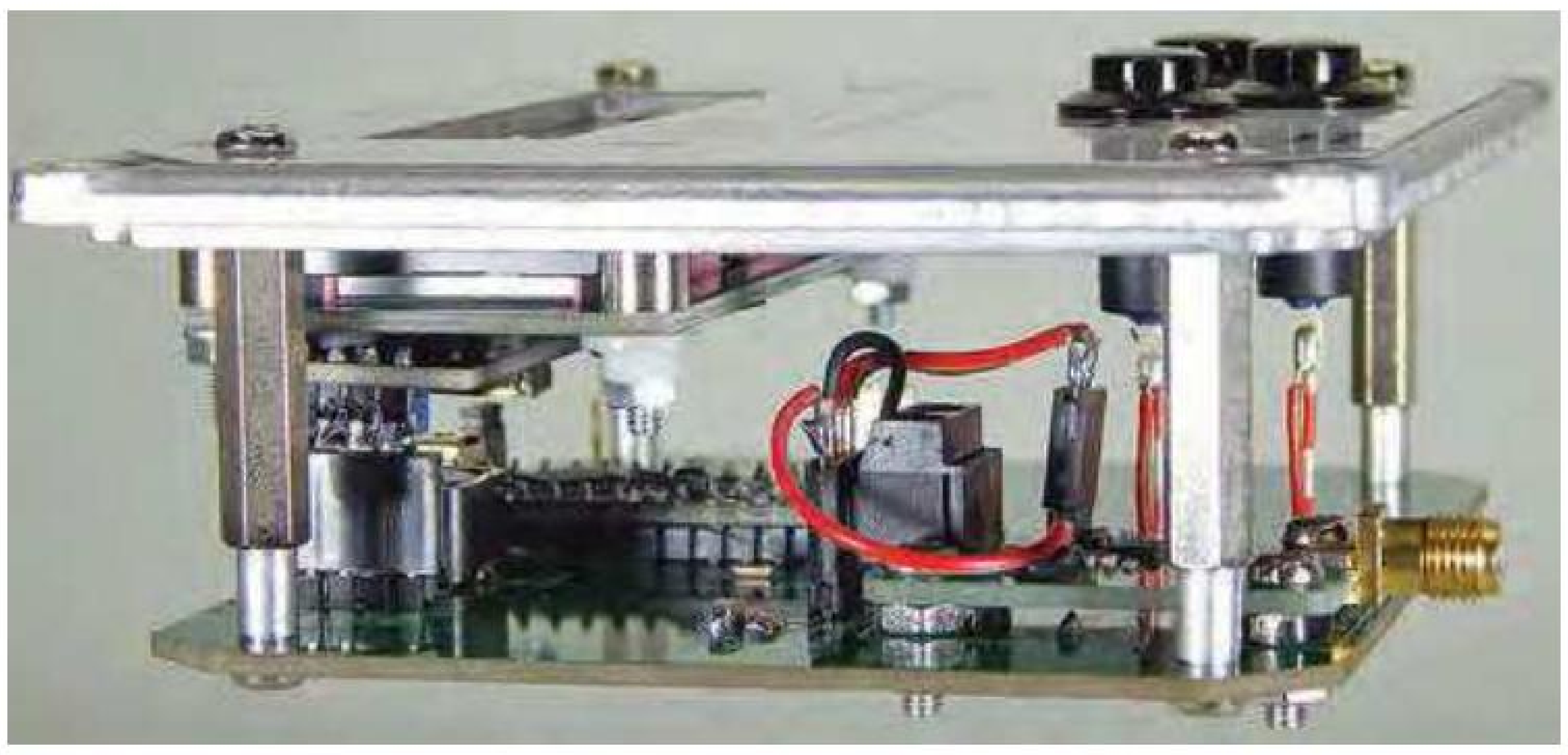
The peak at 2.5GHz is presumably related to the components (and possibly the PCB tracks) at the input of the

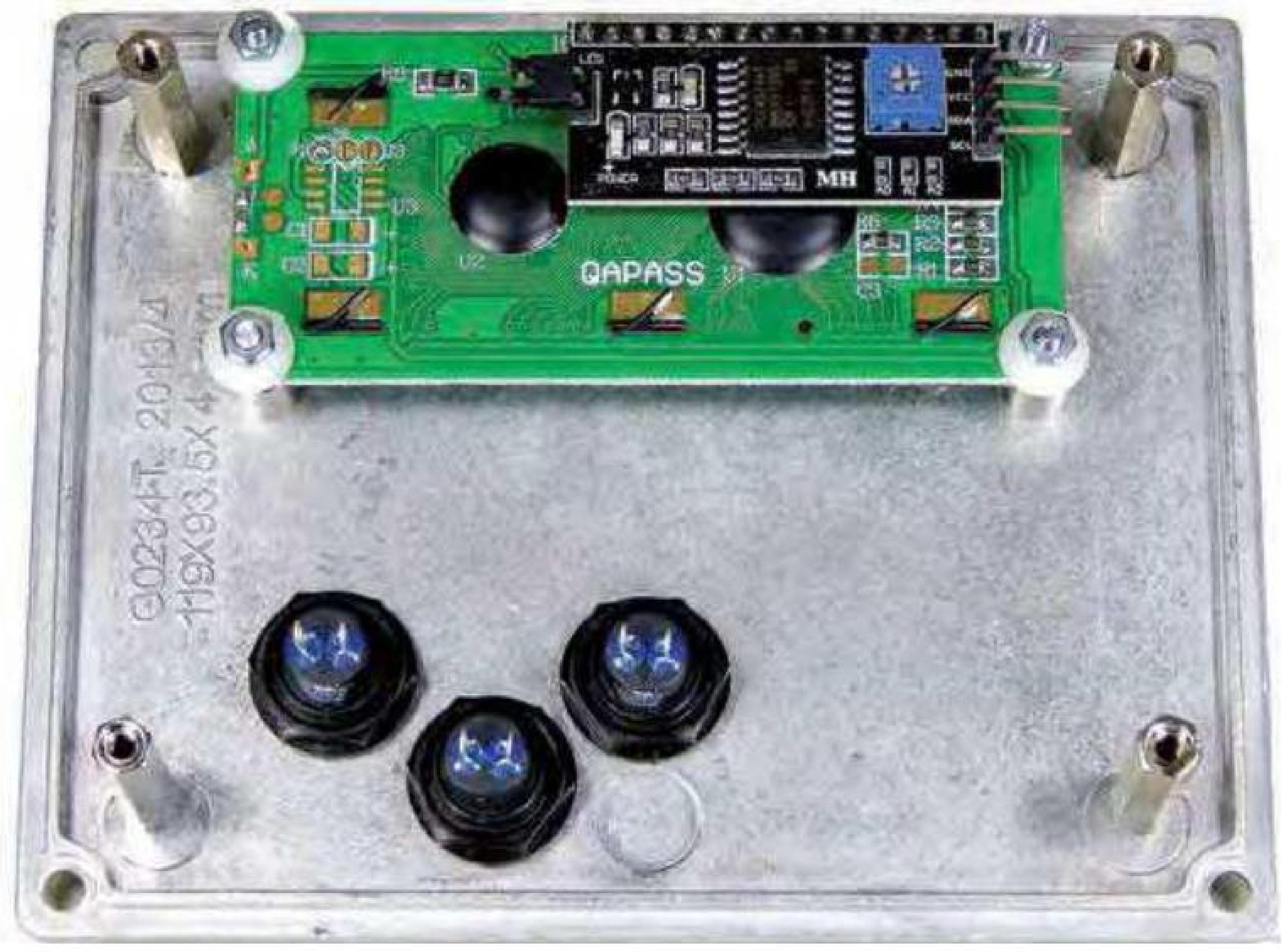


This photo is from the same direction as Fig.8 above . . .



. . . while this shot is from the opposite direction.





End-on photo (above) with a shot showing the display board and pushbuttons, obviously before they were wired in! Note how the standoffs are lengthened to make the required spacing between the main board and front panel.

log detector module. We wondered whether the 51Ω input load resistor was responsible, as the AD8318 data sheet suggests 52.3Ω instead. But swapping that resistor out with some 52.3Ω samples we bought did not eliminate the peak. So it's probably a PCB layout issue.

Even with a longer cable between the generator and the *Meter* (allowing for the cable losses), there was still a peak at 2.5GHz. But if you know the frequency of the signal you are measuring (as you usually would), you can use Fig.9 to make allowances for this behaviour.

Suitable attenuators

To make the *Meter* truly useful, you should ideally also get a few inline attenuators.

These can be used to extend its measurement range above +5dBm. Banggood has a range of very compact SMA-SMA fixed coaxial attenuators, for the reasonable price of around £6 each or £12 for three. They are rated at 2W and 0-6GHz, and are available with attenuation figures of 3dB, 6dB, 10dB, 20dB and 30dB.

The 10dB attenuator could be used to extend the range of the *Digital RF Power Meter* to +15dBm (1.26V RMS, or 32mW), while the 20dB unit would extend its range to +25dBm (3.98V RMS or 316mW). Similarly, the 30dB unit would extend its range to at least +33dBm (10.0V RMS or 2W into 50Ω).

I ordered the 10dB, 20dB and 30dB units, and thanks to the COVID-19 pandemic they took about seven weeks to arrive. But they did turn up eventually, and they seem to be well made. They're pictured in the photo below.

As mentioned earlier, when you power up the *Meter*, the external attenuation figure is set to zero – displayed as '00dB' at the right-hand end of the second line of the LCD. When you change the attenuation figure to allow for any attenuator(s) you are using via buttons S1-S3, the *Meter* will display this new figure on the LCD in the same position.

If at a later stage you remove the external attenuator(s) and wish to reset the *Meter's* attenuation figure to zero, this can be done either by using the trio of pushbuttons again, or simply by removing power from the *Meter* for about 10 seconds and then reapplying it.

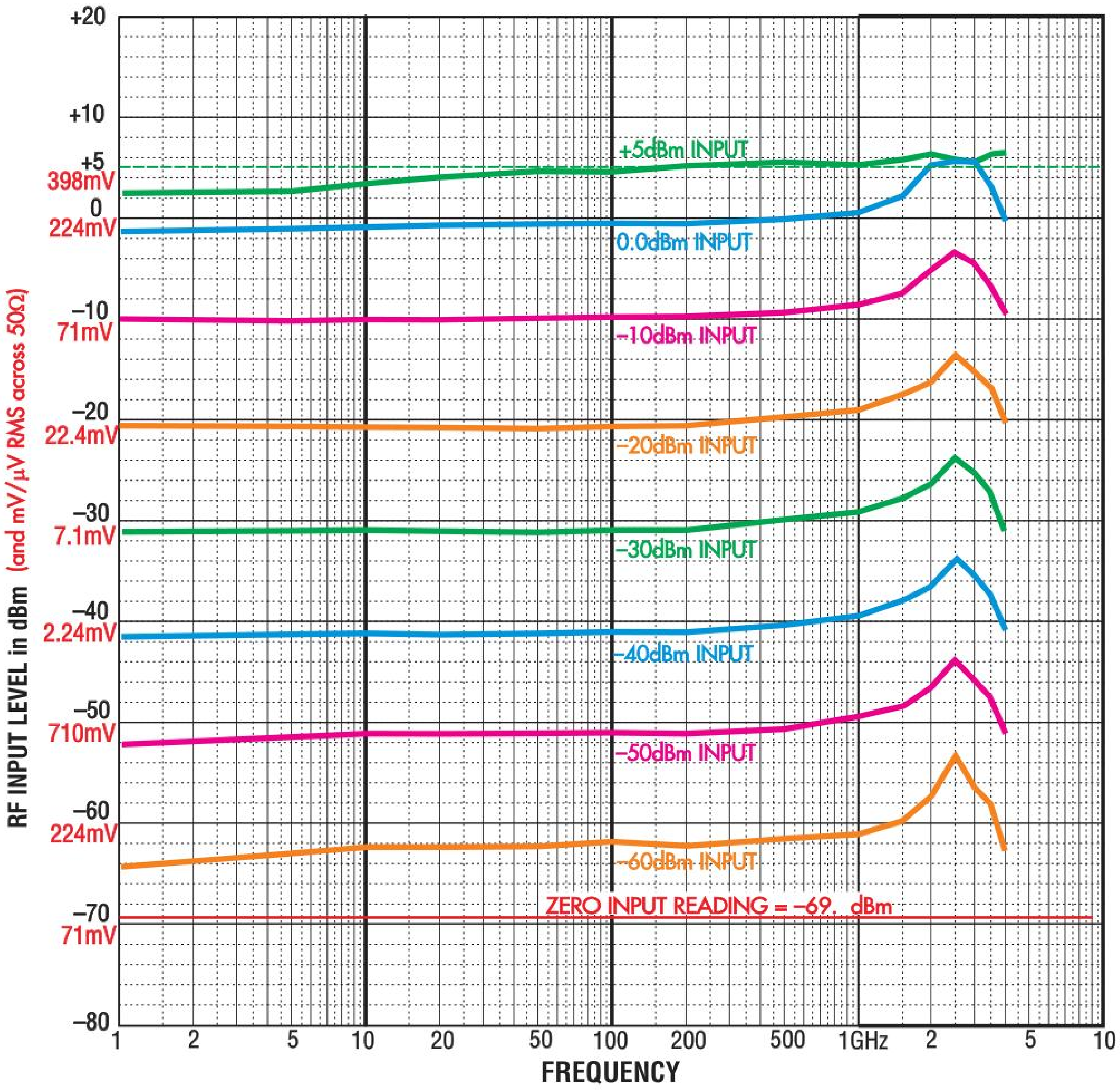
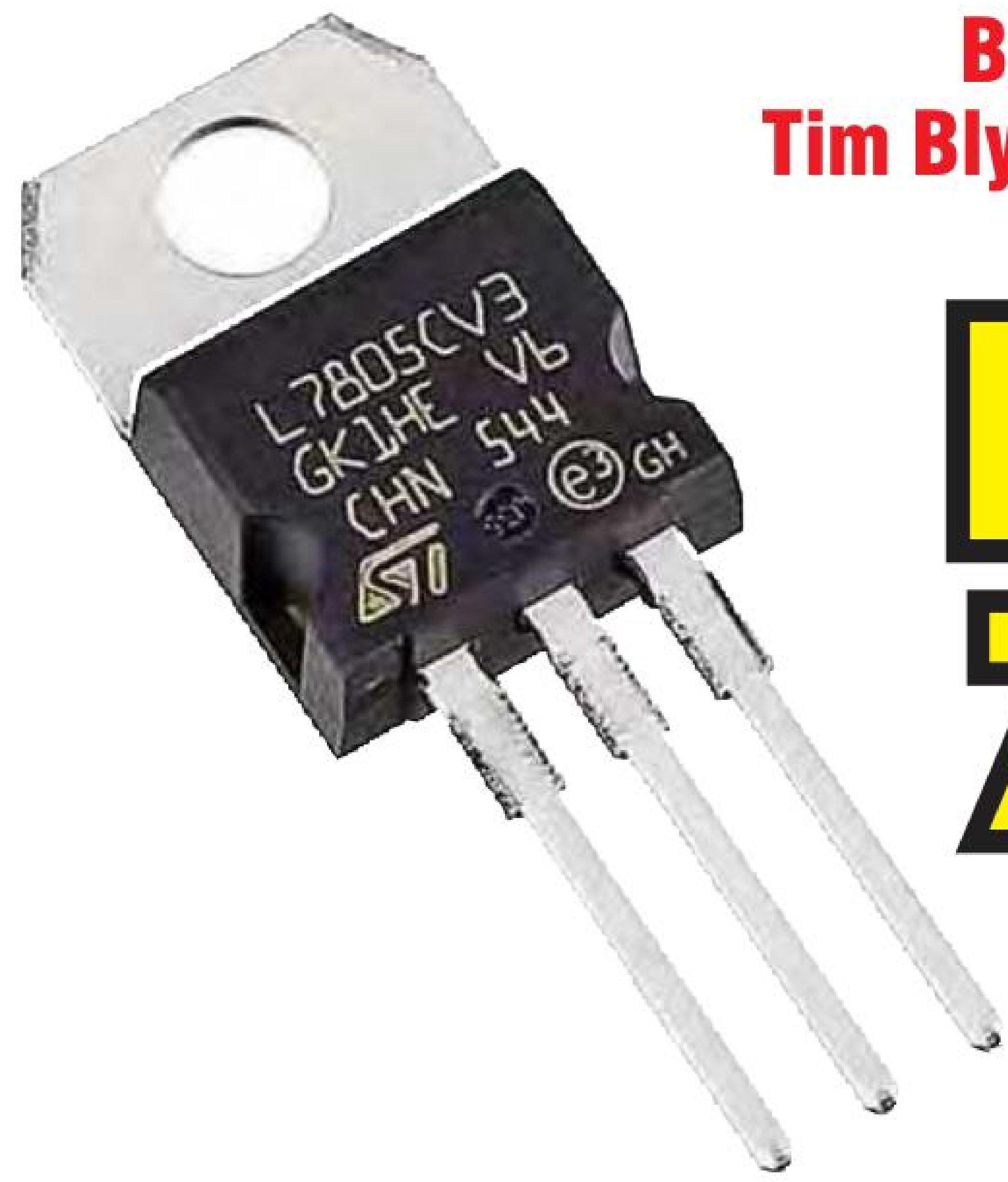


Fig.9: the measured performance of the finished product for nine different input levels over a range of frequencies from 1MHz to 4GHz. The readings are generally within about ±1dB up to 1GHz, but a peak at around 2.5GHz makes readings from higher frequencies less accurate. You can use this diagram to compensate the readings, as long as you know the signal frequency.

TOR -10dB
UATOR 6G-20d
TOR 30dB

A selection of attenuators, in this case 10, 20 and 30dB, which will significantly increase the power handling of your *RF meter*. These were sourced from Banggood, for around £12 for the three.



By
Tim Blythman

Switchmode Replacement for 78xx regulators

The 78xx series of three-terminal linear regulators started as the LM109/309 in 1969. So they've been around for over 50 years, and are still useful today. Their biggest disadvantage is inefficiency, especially with a large input/output voltage difference. If only there was an efficient, drop-in alternative...

We have been using 78xx series linear regulators for decades, and we still use them extensively today.

There is no doubt that they are a simple and effective way of getting a well-controlled fixed voltage supply between 3.3V and 24V. They're cheap, they're available everywhere and they're easy to use.

For example, our *45V Bench Supply* (see *PE*, October and November 2020) used three 78xx series positive regulators and one 7905 –5V regulator to provide regulated rails for its circuitry.

But being linear devices, they can be inefficient, and this causes two major problems. Not only is much of the supplied energy wasted, but it must be adequately removed from the device to prevent overheating. In other words, more inefficiency means more dissipation and more dissipation means more heatsinking is required.

Of course, there are plenty of switchmode ICs which do a similar job, but they almost always require quite a few extra 'support' components, possibly including a bulky inductor. And sometimes selecting the right components is a bit of a 'black art'. Even then, the result may not match the performance of a 78xx; for example, the allowable range of input voltages may be more limited.

This article describes a switchmode regulator that can be used as a direct replacement for a 78xx type regulator in most cases, but with much greater efficiency at higher currents and voltage differentials. It's built on a board that's roughly the same size as a TO-220 package and has the same three connecting leads. And it's relatively inexpensive and doesn't use very many components.

However, we must point out that sometimes, a linear regulator is preferred, mainly because its output does not have switching artefacts (such as high-frequency ripple). Linear regulators may also have better line and load regulation. Switchmode regulators are continually improving in this regard, but there will always be cases where a linear regulator is required.

The ideal solution is often to combine a switchmode pre-regulator with a low-dropout linear post-regulator. That gives you the best of both worlds.

Thus, in the space taken up by two TO-220 parts, you can even implement such a hybrid regulator arrangement by using our design and then passing its output to a discrete linear regulator.

The latter should ideally be a low-dropout type, but a 78xx could be used if maximum efficiency is not required.

Our replacement device

The 78xx we know and love is the one we find in a TO-220 package. This version alone appeared in half a dozen circuits that we published last year. There are also variants in the smaller TO-92 package (the 78Lxx) and SMD TO-252 (78Mxx in surface-mounting D-PAK) packages.

It's the TO-220 package that we're targeting, because if you can get away with one of the smaller variants, the chances are that you don't have too much dissipation to worry about. Also, it's harder to cram the necessary parts into the smaller spaces that these packages offer.

If your intended application has a 78xx bolted onto a chunky heatsink, then you're going to benefit most from our upgrade. And that's precisely what this project is; a drop-in replacement regulator for the hot, inefficient IC that's wasting energy in your circuit.

Our design is easily adaptable for many voltages; it can be used in place of a 7833 (3.3V), 7805, 7806, 7808, 7809, 7810, 7812, 7815 or 7824. It might also be suitable to replace one of the many low-dropout three-terminal fixed regulators on the market (although their pinouts don't always match the 78xx).

The IC at the centre of this design can deliver any voltage from 2V to 24V, with the output voltage of our *Regulator* set by just one resistor value. So this design can replace not just one part, but many.

You might also wonder about parts like the ubiquitous LM317 adjustable regulators.

Features and specifications

- Input voltage 4-30V
- Output voltage...... 2-24V
- Output current...... up to 1A
- Quiescent current. around 80µA
- Efficiency............. typically 90-96%
- Dropout voltage.... 0.5V
- Size...................... equivalent to a TO-220-package device
- Heatsinking........... not required
- PWM frequency.... 500kHz; lower at light loads
- External capacitance required: 1µF+ at input, 22µF+ at output
- Other features ....under-voltage lockout (4V), thermal shut down, over-current/short-circuit protection

They have a different pinout to the 78xx series, so it isn't possible to make a one-size-fits-all solution that addresses both of these families.

While it is possible to fit this device in place of an LM317 in many cases, you would need to make some changes to the surrounding circuitry, including deleting the external resistors which set its voltage.

The design

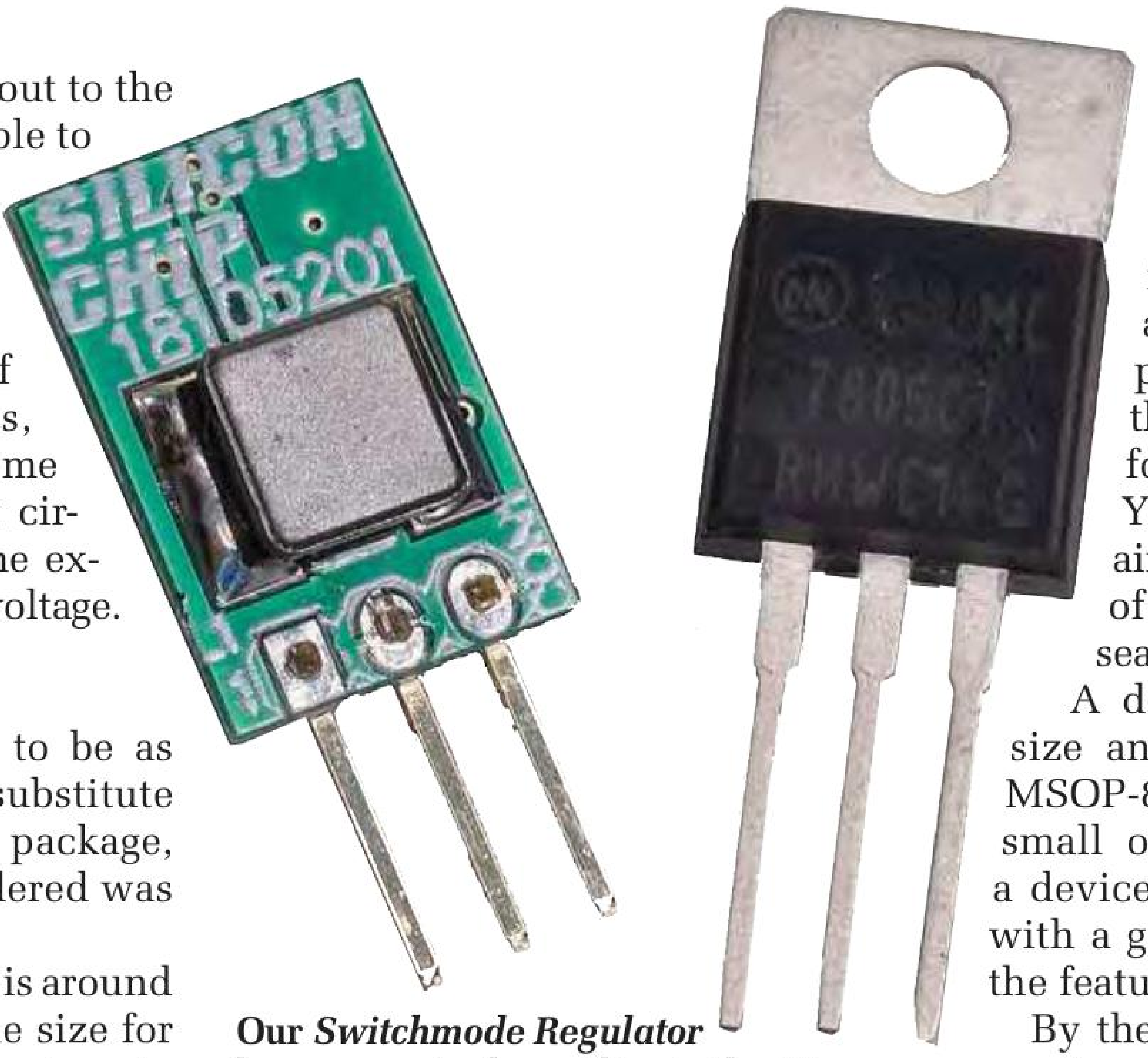
We wanted our *Regulator* to be as close as possible to a direct substitute for the 78xx in a TO-220 package, and the first item we considered was the size.

The body of a TO-220 part is around 10mm × 15mm; a minuscule size for a PCB. But it would not be a drop-in replacement if it doesn't fit in the same space.

We decided to leave off the tab mounting hole, since our design will not need to dissipate anywhere near as much heat. So there is no need to attach it to a heatsink.

While this does also remove the option of using a mounting screw to secure the part, our *Regulator* uses sturdy pin headers which are thicker than the leads on most discrete parts. If absolutely necessary, silicone sealant or other adhesive can be used to provide mechanical support.

In any case, the *Regulator* PCB with all its parts is typically around half the weight of a TO-220 device, so the mechanical stresses will be less.



Our *Switchmode Regulator* has a very similar outline to the 78xx linear regulator it is intended to replace. With careful choice of parts, the thickness can be kept much the same too. If you have space available, you may wish to use a larger inductor or larger capacitors to improve its performance.

With the PCB size set, we started looking for the best switchmode regulator IC to use. We needed to choose one which we could fit on this small PCB, including all the required supporting components. We found it difficult to find suitable parts that could work up to the nominal 35V input that the 78xx series can tolerate. In the end, we settled for a part with a 30V rating, as this covers most use cases.

We considered using a device in a user-friendly SOIC-8 SMD package, but one of these would take up around a quarter of the available space on the PCB.

Other parts we found came in QFN (quad flat no-lead) and DFN (dual flat no-lead) packages, but we decided that these would be too difficult for many people to solder. You need a reflow oven or hot air station to have much chance of success, so we limited our search to parts with leads.

A decent compromise between size and ease of soldering is the MSOP-8 package (eight-pin micro small outline package). We found a device that came in this package, with a good compromise of most of the features we wanted.

By the way, MSOP packages have varying pin pitch, sometimes 0.635mm (the same as SSOP and TSSOP) and sometimes even smaller, at 0.5mm. But they're also narrower than SSOP and TSSOP, so are one of the most compact packages that can be hand-soldered without too much difficulty.

Switchmode operation

If you aren't familiar with the operation of switchmode regulators, see our panel, *How switchmode regulators work*. This also explains some of the other design considerations we had to take into account.

While sorting through the (huge number of) switchmode regulator ICs that are available, we looked at several features. First, high-frequency operation is necessary. This means

How switchmode regulators work

There are many types of switchmode regulators in use today. This includes step-down (buck), boost, flyback, buck/boost, SEPIC, resonant and fully isolated types.

But step-down/buck is probably the most common configuration and is also, in a sense, the simplest (with boost not far behind). This is a step-down/buck design.

A linear regulator reduces its output voltage by simply introducing a controlled resistance in series with the load. If the input voltage is twice the output voltage, this means that 50% of the power going into the regulator is turned into heat. That means poor efficiency.

If your aim was to vary the power to something like an LED or lamp, which only responds to the average current, you could get much greater efficiency by applying the full input voltage to it but only doing so 50% of the time. This could be done using pulse-width modulation (PWM), and indeed that is how most DC lamp dimmers and simple motor-speed controllers work.

The voltage is normally switched by a transistor, with the transistor either fully off (and passing no current) or fully on (dropping no voltage). Little power is lost in the switching element, with real-world efficiencies coming quite close to 100%.

But such an arrangement is not suitable for powering ICs or other devices which expect a more-or-less constant supply voltage. Thus, to get a similar efficiency to the PWM approach when powering such devices, we need to 'filter out' the rapidly changing part of the waveform (the AC component), giving us just an average voltage level (the DC component).

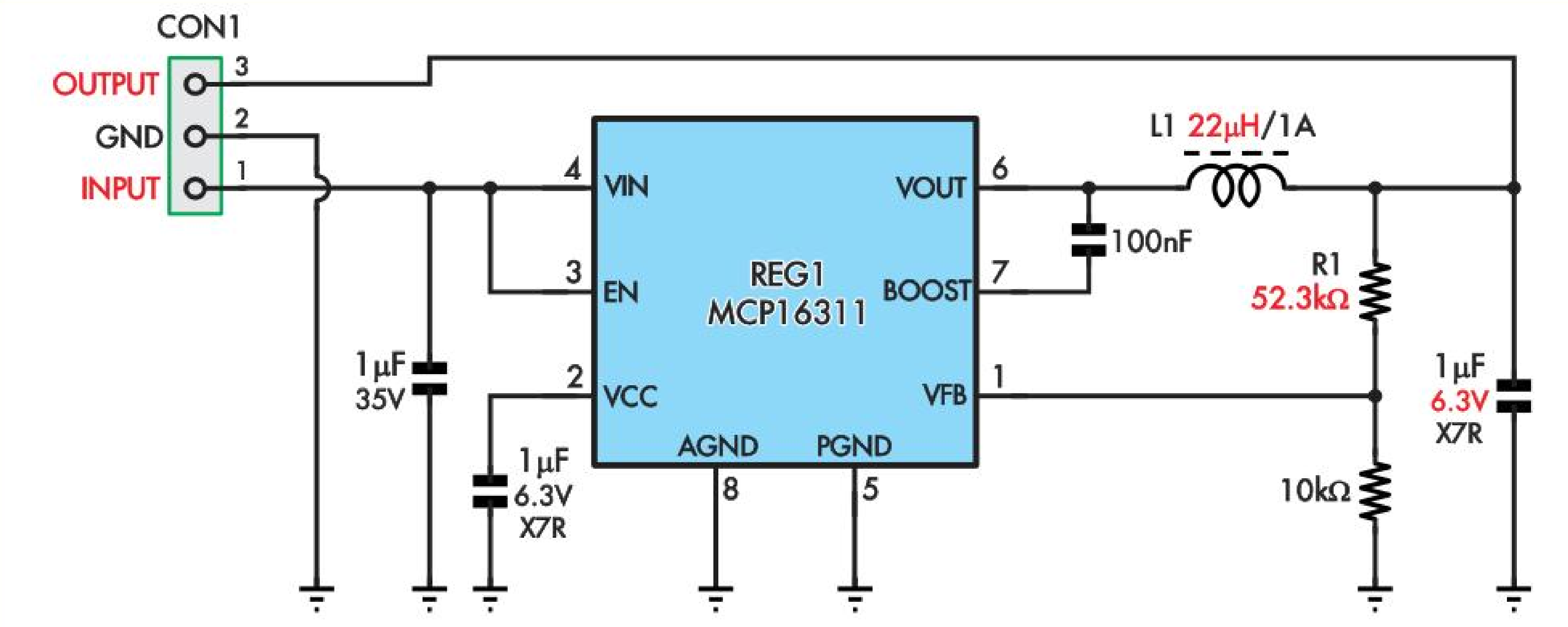
An LC low-pass filter is a simple way to do this. We can't use an RC filter since we would have half the voltage across the resistor, so efficiency would be no better than a linear regulator. But with an LC filter, energy is stored in both elements (the inductor and the capacitor). Most of that is returned later, so losses and heating are minimal.

In the case of the inductor, excess energy is briefly stored in its magnetic field.

One way to think of this approach is that applying pulses of voltage to an inductor forms something like a constant-current source. At the same time, the capacitor makes the load impedance very low at high frequencies, resulting in a fairly unchanging voltage across the load, despite the pulses applied by the transistor.

There will still be some amount of ripple present at the load, but with the correct choice of components, it can be reduced to a manageable amount. In fact, the amount of tolerable ripple dictates the required switchmode frequency and capacitor and inductor values.

The best way to reduce ripple is to use the largest inductor and capacitor values possible. In practice, size is an issue, particularly with inductors, so we are forced to compromise (too large an inductor can also affect the regulator's response to load transients).



High-efficiency Swtchmode Regulator (5V)

Fig.1: the circuit of the *Regulator* is just about straight out of the MCP16311 data sheet, except that the input and output capacitors are lower than recommended. That's because these are supplemented by external capacitance on the host board. The values in red need to change for a different output voltage.

that a lower inductor value is needed, which reduces its physical size. A higher frequency also means less ripple and noise.

We also looked for parts which operate synchronously, rather than requiring an external diode. While it is only one extra part, the diode does carry a fair amount of current, so choosing a synchronous part means that some space and dissipation is saved. The voltage drop across the low-side MOSFET (which replaces the diode's function in synchronous designs) is less than that of the diode.

Ultimately, we settled on the Microchip MCP16311. It has a switching frequency of 500kHz and operates synchronously with a minimum number of external components for an adjustable output. As noted earlier, it can operate with up to 30V on its input.

We initially tried to lay out the PCB using 3216-size (1206 imperial) passive components. These measure 3.2mm × 1.6mm, but were too large, so we switched to 2012-size (0805 imperial) parts measuring 2.0 × 1.2mm. These save a significant amount of space on the PCB, but aren't too much harder than 3216-size parts to solder.

The footprints that we've provided on the PCB are actually a tiny bit larger than 3216/1206 parts, so you might be able to use the slightly larger 1206 parts anyway.

The circuit

The circuit for our design is shown in Fig.1, with the components for a 5V output. IC1 is the MCP16311 integrated switchmode controller. It works with 4.4-30V at its input (pin 4, VIN) and can deliver 2-24V at up to 1A. Pin 3, the enable (EN) input, is tied to VIN so that the IC is enabled as long as there is a sufficiently high supply voltage.

The input supply is bypassed by a 1µF capacitor. While this is less than the recommended capacitance in IC1's data sheet, any application using a 7805 requires an external bypass capacitor anyway, which will supplement the capacitance fitted to the PCB.

Pins 5 and 8 are connected to ground, with pin 5 being the high-current return for the synchronous switch, while pin 8 is the low-current reference ground to which the output voltage is referred. Both are connected to large copper pours on the PCB.

IC1 has an internal low-voltage regulator for its control circuitry, which should be bypassed by a 1µF capacitor connected between pin 2 and ground. This pin sits around 5V, so a 6.3V capacitor is adequate.

Pin 1 is connected to IC1's internal regulator feedback circuitry. The voltage at pin 1 is compared to a precision 0.8V reference, so this pin should be connected to the midpoint of a voltage divider between the output and ground. The ratio of this divider sets what fraction of the output voltage is seen at pin 1 and thus dictates the output voltage.

The MCP16311 data sheet recommends a 10kΩ resistor for the lower part of the divider, so changing the output voltage is simply a case of setting the upper resistor.

For a 5V output, the upper resistor should ideally be 52.5kΩ. While changing this resistance will set a different output voltage, for optimum performance, other components must be adjusted too.

In practice, 52.3kΩ is the closest commonly available value, from the E96 (96 values per decade) series. This gives a nominal 4.984V output. For comparison, a 51kΩ resistor (found in the more common E24 series) would give a nominal 4.88V output.

Unless you need a precision voltage reference, either of these would be close enough for most 5V supplies. You probably should not use a switchmode device as a precision reference anyway!

Pin 6 is the switch (SW) terminal, which is connected to the two internal MOSFETs. One switches the output to ground (pin 5), the other to VIN (pin 4). A non-synchronous part would require an external diode (typically a schottky diode) in place of the lower transistor, to allow inductor current to circulate while the upper MOSFET is off.

Between the switch terminal and the output is an LC low-pass filter comprising a series inductor and a capacitor to ground. Like the input capacitor, we're using a lower capacitor value than recommended given that more external capacitance will be fitted. However, it would be possible to fit a higher capacitance in the space available if necessary.

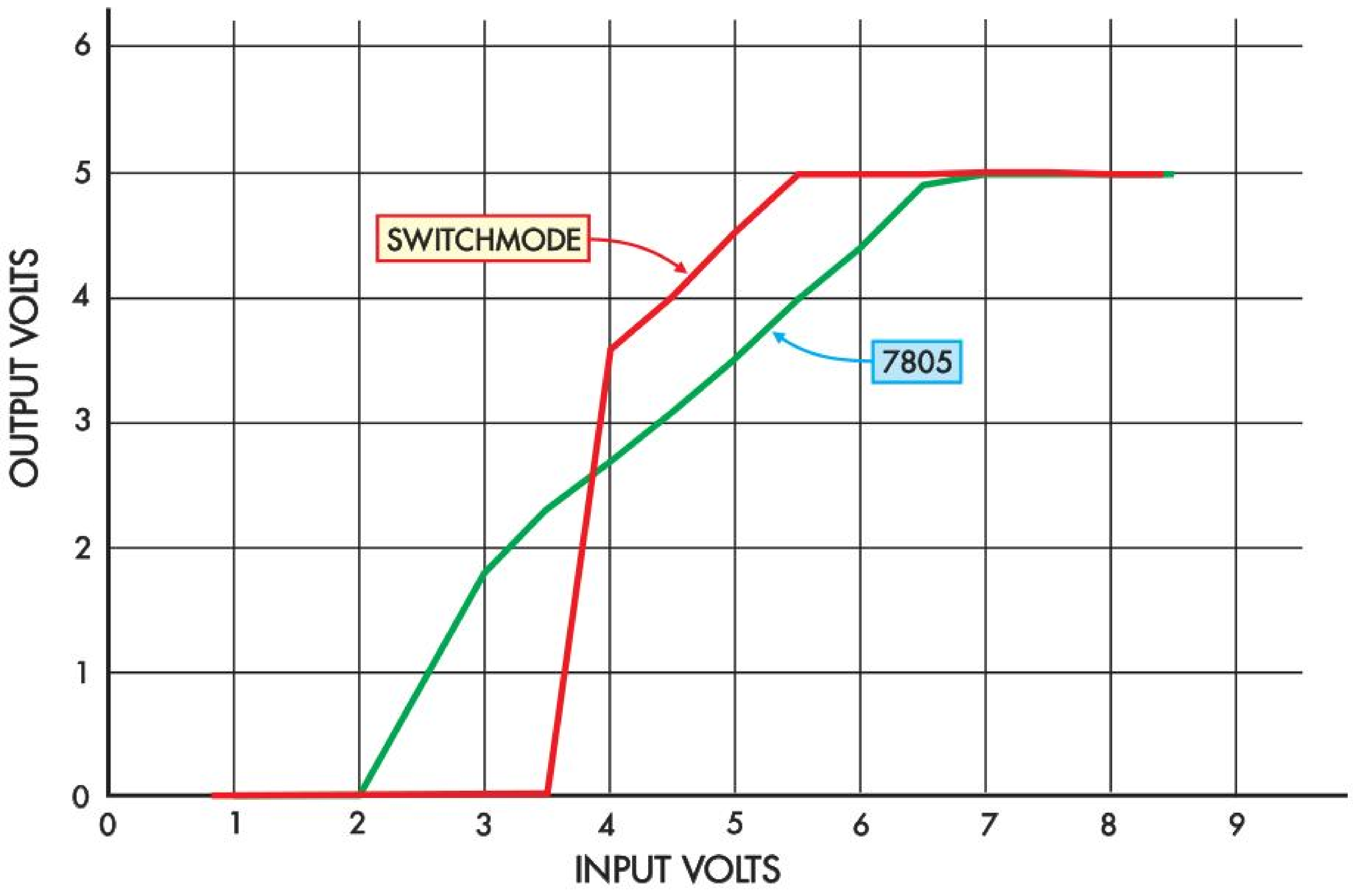


Fig.2: the *Switchmode Regulator* does not operate with an input supply below 4V. At 4V and above, though, it has a much lower dropout voltage than the 7805 and attains a 5V output with only 5.5V at its input (ie, 0.5V dropout). The 7805 needs nearly 7V on its input before it is in regulation.

The output of the LC filter is fed to the output pin of CON1, which forms the interface with the external circuitry; its other two pins are connected to the VIN pin of IC1 and the ground pour. This output voltage is also fed to the upper resistor in the feedback voltage divider mentioned earlier.

The final component on the board is a 100nF capacitor between pins 6 (switch or SW) and pin 7 (BOOST). Because the internal high-side MOSFET is an N-channel device for maximum efficiency, it needs its gate to be brought above its source to conduct. As the source is connected to the SW pin, a voltage above SW (and possibly above VIN) is required to drive its gate.

An internal charge pump provides this higher voltage, which is stored in this 100nF capacitor until it is needed to switch the MOSFET.

The overall operation is as follows. IC1 produces a pulse-width modulated (PWM) square wave at the SW pin (pin 6) which is filtered by the LC circuit. The output voltage is monitored by the voltage divider connected to pin 1, which causes IC1 to change its PWM duty cycle to maintain the desired output voltage.

With a light load at its output, IC1 can also 'drop' or skip PWM cycles, reducing power consumption.

Three-pin header CON1 has 0.1-inch (2.54mm) spacing, to match a TO-220 package.

Setting the output voltage

The MCP16311 data sheet recommends different inductors for different output voltages. The rule-of-thumb value is 4.5µH per volt at the output.

In choosing an inductor, keep an eye on the DC resistance specification too. Values around 100mΩ are recommended, meaning that the inductor will drop 0.1V, dissipating 100mW when the regulator is supplying 1A. If you are planning to run your regulator near 1A, this will probably be the biggest loss.

Another critical point is the voltage rating of the output filter capacitor. You need a 6.3V or higher rating for a 5V output, but we've specified 50V for all capacitors to keep things simple.

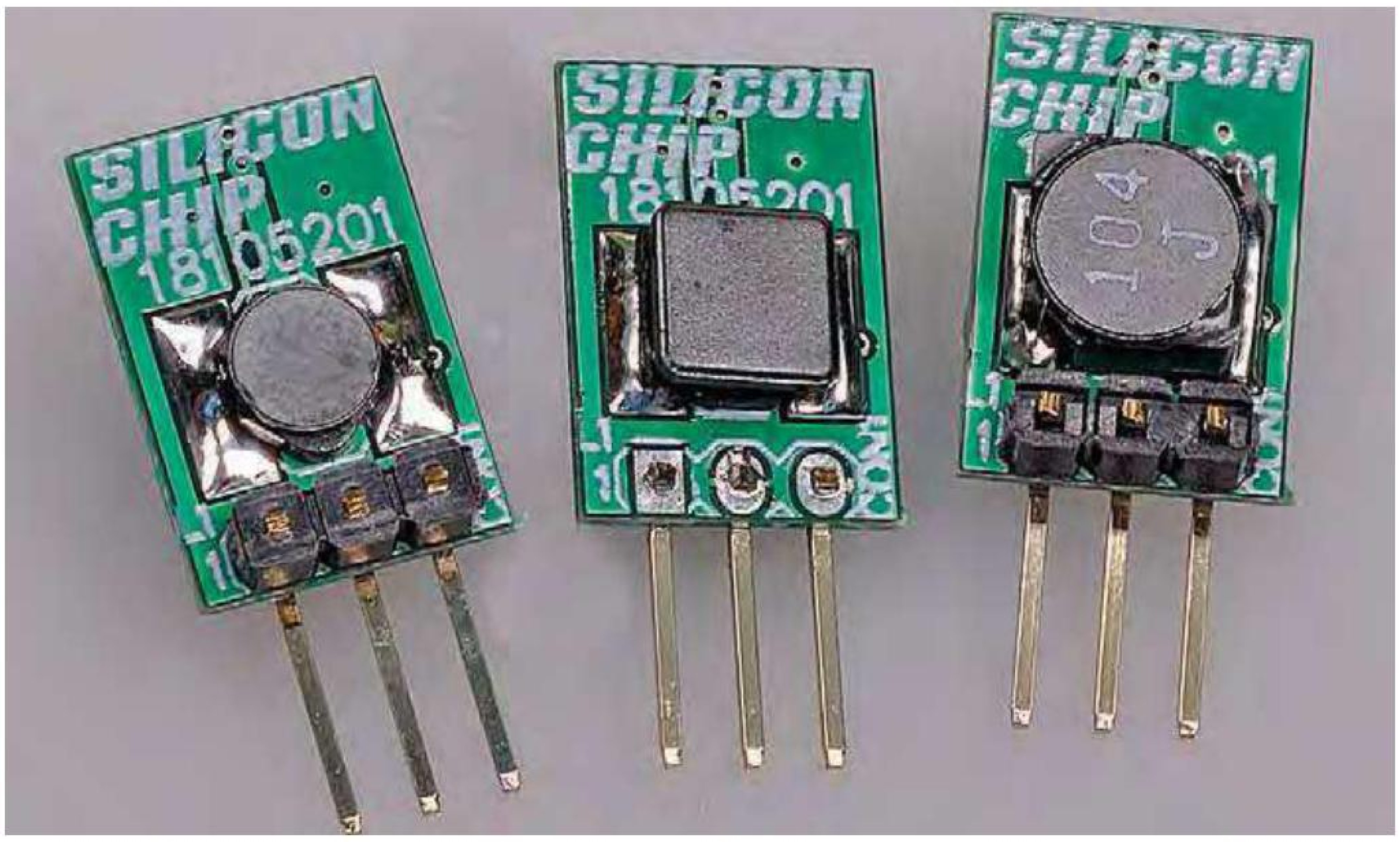
Advanced constructors may wish to use devices with a lower voltage rating but higher capacitance, as long as they still have a sufficient voltage rating for their particular role.

Table 1 shows some choices for both the top resistor value (from both the E24 and E96 series) and also a suggested inductor value.

Desired V_{out}	R1 (E96)	Nominal V_{out}	R1 (E24)	Nominal V_{out}	L1
3.3V	31.6kΩ	3.328V	30kΩ	3.2V	15µH (eg, SRN6028-150M)
5V	52.3kΩ	4.984V	51kV	4.88V	22µH (eg, SRN6028-220M)
6V	64.9kΩ	5.992V	62kΩ	5.76V	27µH (eg, ASPI-6045S-270M)
8V	88.7kΩ	7.896V	91kΩ	8.08V	39µH (eg, ASPI-6045S-390M)
9V	102kΩ	8.96V	100kΩ	8.8V	39µH (eg, ASPI-6045S-390M)
10V	115kΩ	10V	110kΩ	9.6V	47µH (eg, SRN6028-470M)
12V	140kΩ	12V	130kΩ	11.2V	56µH (eg, SRN6045TA-560M)
15V	178kΩ	15.04V	180kΩ	15.2V	68µH (eg, TYS6045680M-10)
24V	287kΩ	23.76V	300kΩ	24.8V	120µH (eg, SRN6045TA-121M*)

** current rating is 850mA, so don't draw more than this (the output voltage may drop before reaching that level). For more current, you can probably get away with a 100µH inductor, part code ASPIAIG-S6055-101M.*

Table 1: Component choices



Left to right: 3.3V, 5V *Regulator* and 12V *Regulator*. Note the inductor is much larger for higher-voltage versions. This version is only 6mm thick, which is more than the 5mm of many 78xx regulators, but still slim enough to fit in most places where one would be used, especially as no heatsink is normally required.

Note that the E24 resistor values do not allow for a high level of accuracy, but may still be close enough, depending on your application.

Performance

Naturally, we ran some tests to ensure that the *Regulator* has equivalent performance to its linear predecessor.

As per the data sheet recommendations, we connected around 10µF extra capacitance at the input and 22µF at the output.

Efficiency is very high compared to a linear device. We connected our prototype 5V Regulator to an 8Ω load (a wirewound power resistor), drawing a nominal 625mA. For low values of input voltage (up to around 12V), efficiency was 96%, dropping off above 12V.

This agrees well with the information in the MCP16311 data sheet. Our calculations suggest that well over half of these losses are simply due to dissipation in the inductor's DC resistance. Hence, the importance of low DC resistance in this part.

During this test, we noted the *Regulator* was warming up above ambient, but was never too hot to touch.

Another quick measurement indicated that the quiescent current of the *Regulator* (under no-load conditions) is around 80µA, close to the value from the data sheet, and a lot less than a 78xx regulator at around 5mA (60 times higher!).

Fig.2 shows how the output voltage varies with the input voltage, comparing the *Regulator* with the expected performance of a standard 7805. This also indicates the dropout voltage.

Interestingly, the 7805 passes more voltage at very low input voltages.

This is not unexpected, as the MCP16311 does not even come out of the under-voltage lockout until its input reaches around 4V. Once it starts up, it has a much lower dropout, needing an input of only 5.5V to supply 5V at the output; a dropout voltage of around 0.5V.

On the other hand, the 7805 is not regulating correctly until its input reaches around 7V; a 2V dropout.

In battery-powered applications, both the lower quiescent current and the low dropout voltages are big advantages. Not only does the higher efficiency mean that less energy is wasted, but the *Regulator* is also capable of operating with much lower input voltages, making better use of the same battery.

One advantage of the MCP16311's low-voltage shutdown feature is that in a battery situation, the 7805 would continue to pass current, completely flattening the battery (which could be fatal if it's a rechargeable type), while the MCP16311 will switch off when its input gets too low, preventing this.

Since the output is below 5V by the time the input reaches 4V, the connected circuit will probably not be operating to specification anyway.

Scope1-Scope4 show more details of the circuit's performance. Scope1 shows that the Regulator takes around 350µs to start up, which is quick enough for most applications. Scope2 shows output ripple.

This is one area where the 7805 will be superior, although this small amount of ripple is tolerable for most applications.

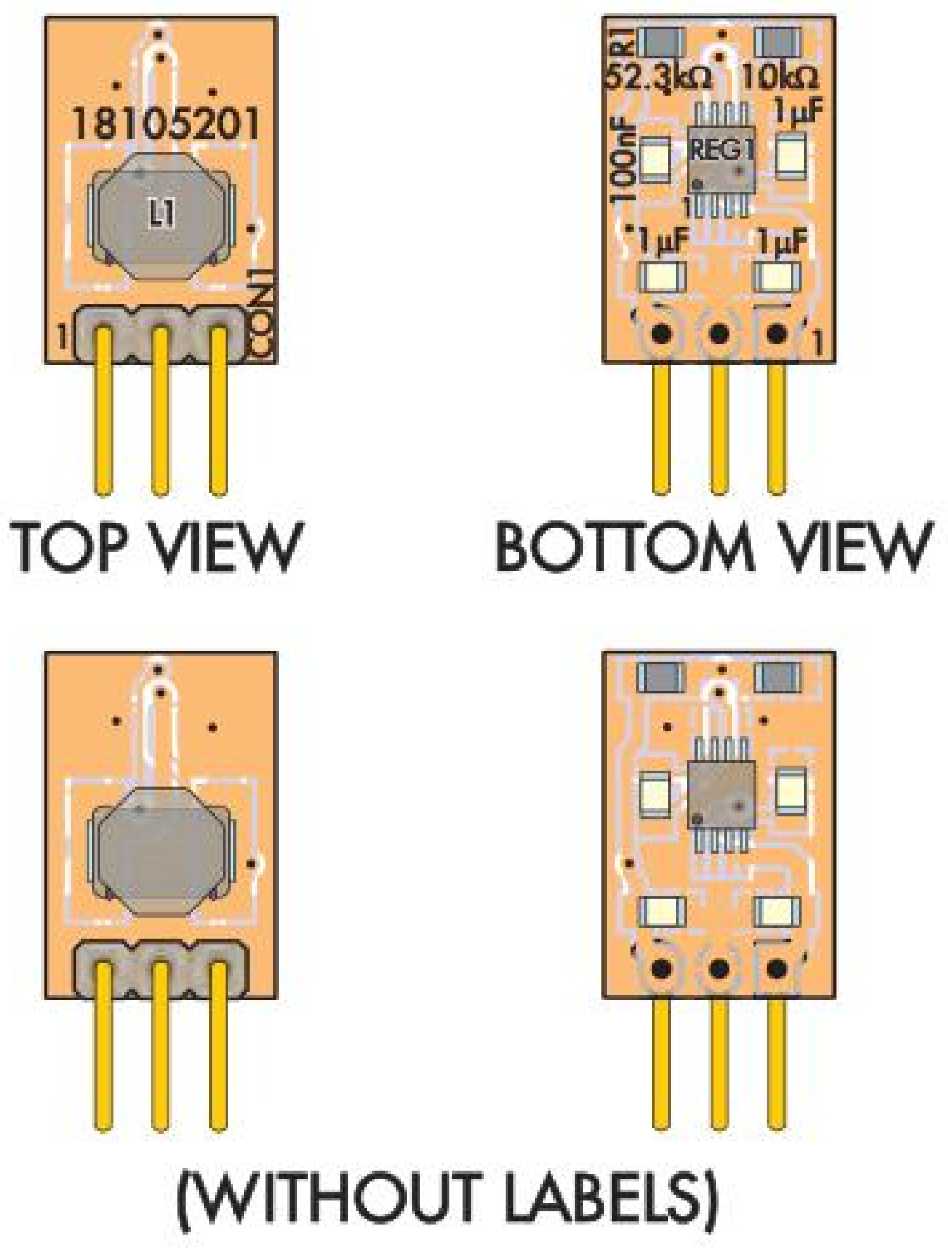
Scope3 and Scope4 show the response to load and line changes; the output varies by around ±150mV for a 625mA load step, recovering in less than 100µs, while line regulation is around 1%, ie, an output variation of around 17mV for an input ripple of 1.88V.

Construction

Taking note of what is described above, choose your components before starting construction. Many of the components are quite small, and their marking will be barely legible. The capacitors will probably be unmarked, so take care not to mix them up (or lose them!).

Check that you have the appropriate tools for working with small surface-mounted components.

At a minimum, we recommend a fine-tipped soldering iron (preferably with adjustable temperature), a pair of fine-tipped tweezers, a magnifier as well as some flux paste and solder braid (wick).



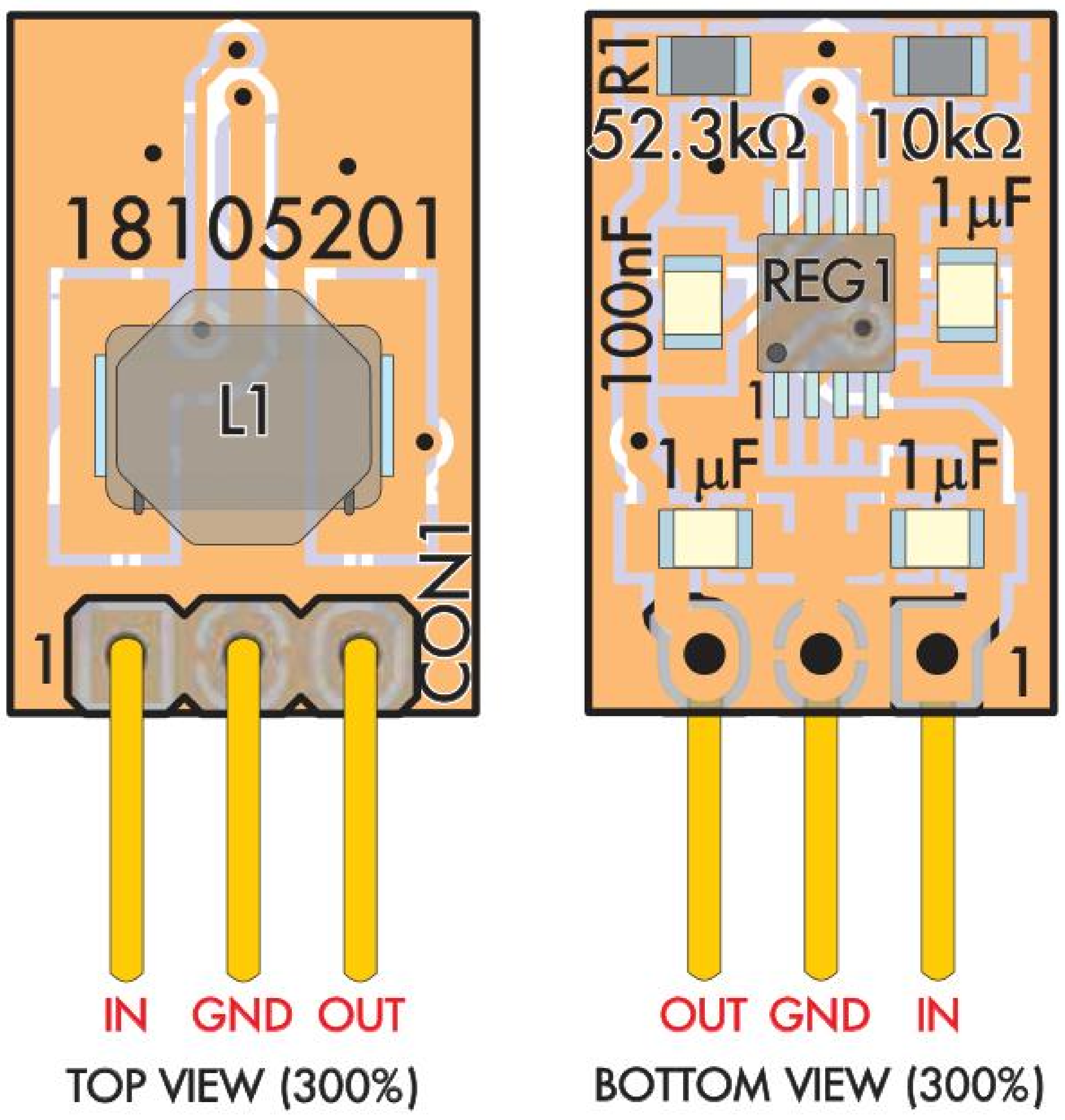


Fig.3: we've shown the component overlays same size (above) as we normally do but thought a very-much-enlarged view (at right) would help you with assembly. Inductor L1 is fitted to the top side of the PCB, opposite to the other parts. It is easiest to solder IC1 first, as access to its pins is not as good once the surrounding parts are in place. The part that controls the output voltage is resistor R1 at upper left. Here it is a 52.3kΩ resistor, to give a 5V output. Pin header CON1 can be fitted to either side, depending on the needs of your application. This can be fitted last, so you can test fit the board before soldering it.

Something to secure the very small PCB would be handy. If you don't have a PCB clamping tool, then Blu-Tack may be sufficient.

The *Regulator* is built on a double-sided PCB coded 18105201, available from the *PE PCB Service*. It measures 15 × 10mm and is 0.6mm thick (a standard PCB is 1.6mm thick, which would make the device 1mm thicker). Refer to the PCB overlay diagram (Fig.3) during construction, to see which parts go where.

IC1 has the finest pins, so start by fitting it. Check and confirm where the pin 1 dot is and align it with the markings on the PCB. If you have CON1 at the bottom then IC1's pin 1 is at lower left. If you cannot find a dot, then the part may have a chamfer along one edge; this edge should be closest to CON1.

IC1's pins are on a 0.65mm pitch with only a 0.2mm spacing. You will probably bridge some of the pins while soldering it, so the solder braid is essential.

Apply some flux to the pads and hold the IC in place with the tweezers. Solder one pad down (or even one side if your iron tip is broad). Check and double-check that all the pins are entirely within their pads; if they are not, then they may short to adjacent pads even after any solder bridges are removed. Also check that the part is flat.

Once you are sure of this, solder the pins on the other side. Don't be concerned about bridges; in this case, they are almost inevitable. Just ensure that each pin is soldered to its correct pad in some fashion.

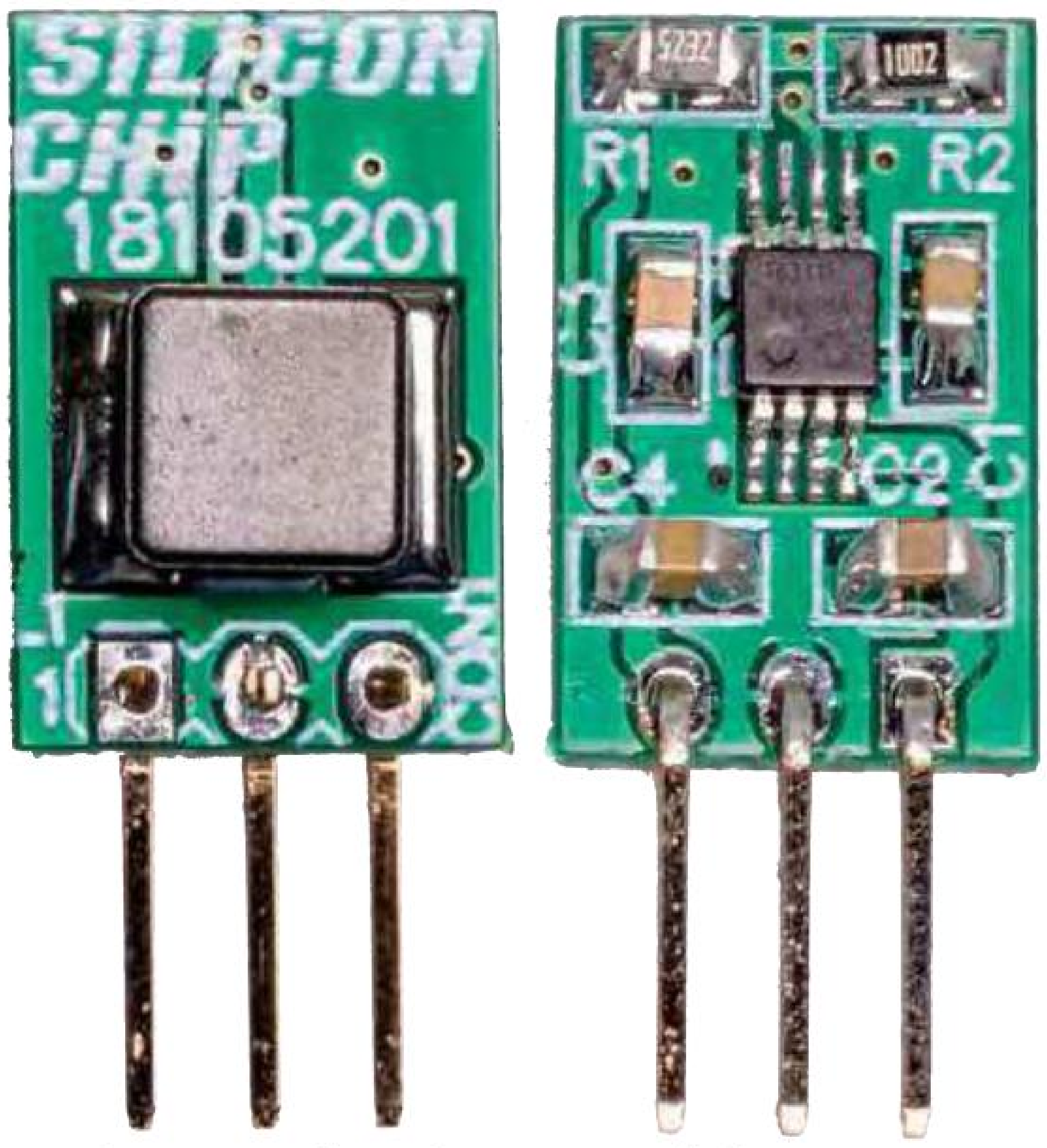
With the IC soldered in place on both sides, you can clean up any bridges. Apply some more flux paste to the pins and press the braid against the pins with the soldering iron on one side. Gently draw the braid away from the part. It should draw up any excess solder, leaving a clean fillet. Inspect this with the magnifier and compare it to our photo above.

Apart from IC1, none of the parts are polarised, so do not be concerned about the orientation after IC1 is installed. Follow with the 100nF capacitor which goes near IC1's pins 1 and 8. Apply flux to the pads and solder one lead only. Confirm that the part is flat and square within the pads before soldering the other lead. Go back and retouch the first lead with some fresh solder or a bit of extra flux.

Use the same technique to fit the three 1µF capacitors. While they don't all need to be 50V types, the price difference is small, so it's easier to just use 50V types for all three as stated in the parts list. That also makes assembly easier since you don't have to worry about which one goes where.

The two remaining parts on this side are the resistors. Fortunately, these are usually marked so are more difficult to mix up. The 10kΩ resistor will be marked as '103' or '1002'. The other resistor value will vary depending on your selected output voltage. For the 52.3kΩ resistor we've recommended for a 5V output, expect a code of 5232.

The last component, inductor L1, is on the other side of the PCB. So now is a good time to clean up any flux residue on the top before flipping the PCB over. If you don't have a dedicated



Again, reproduced very much larger than real life, these photos show front and back of the *Regulator* – in this case set up to replace a 7805 (5V) regulator. Changing the regulation voltage is as simple as changing R1 and L1 to suit.

flux solvent, isopropyl alcohol may work (assuming you can get some at a reasonable price!).

In any case, take care, as many of these cleaning substances are flammable. Allow the PCB to thoroughly dry before resuming soldering.

L1 is a larger part and will generally have more thermal mass, so may require more heat. We've sized the pads for a nominal 6mm × 6mm part although an inductor up to 8mm × 8mm footprint may fit. In this case, you may need to apply heat to the inductor leads.

The technique is much the same as for other two-lead parts. Apply flux, solder one lead, check that the part is where you would like it and then solder the remaining lead. Then clean up the flux that's been applied to this side of the PCB.

You may need to install straight or right-angle headers for CON1, depending on how you wish to use the *Regulator*. We've fitted right-angle headers to our units to make them install just like a TO-220 device. This is also ideal for use on a breadboard.

If using right-angle headers, check which side is the best fit (they can be soldered on either side), in case space is tight in your application.

We fitted the headers at the rear (IC1 side) of the PCB by removing the pins from the plastic frame and threading them into the frame from the other side. This allows the pins to be held in position while soldering.

This arrangement can also be used to mount the *Regulator* flat against the PCB by bending the leads a further 90°, just as you would for a discrete part, but a more rigid option would be to mount a straight header at the back.

This may not work if you have components very close to where the *Regulator* will need to mount, but will be a lot more secure as the shorter leads will not be able to flex as much.

Testing

One of the worst things that could happen is that R1 is open circuit, which would mean that IC1 is not able to regulate the output as it cannot see any voltage at its output; effectively, the input voltage will appear at the output.

If this is your first foray into surface-mounted parts, you might want to double-check your soldering against our photos. You should ideally also test that the *Regulator* works correctly before deploying it to your circuit. 3-pin header CON1 will make it easy to plug into a breadboard or use jumper wires to rig up a test circuit.

Note that the front of the *Regulator* is the side with the inductor and the CON1 header and pin 1 markings are on this side.

Apply 4-30V to pin 1 of CON1 (with respect to GND at pin 2). Use a current-limited supply if possible (eg, a bench supply) or series resistor to limit the current; this will minimise damage in the event of a fault with the circuit.

You should be able to measure the desired output voltage at pin 3. You may also like to load the output (for example, with a resistor) to check that the circuit works under load. If it works as expected, you are ready to solder it into your final circuit.

Installation

Because it is intended to replace a single component, the *Regulator* could be used in any number of designs, so we can only offer general advice.

Any design using a 78xx or similar should have separate bypass and filter capacitors already included.

We've put some modest capacitance on the *Regulator* PCB, but as mentioned earlier, not as much as recommended by the MCP16311 datasheet; mostly due to space considerations.

The MCP16311 should ideally have at least 2µF at its input and 20µF at its output; we've provided around 1µF for each. Thus an extra 1µF on the input and at least 22µF at the output is recommended.

One option to add more capacitance directly to the *Regulator* PCB is to stack capacitors vertically. We've even seen part manufacturers do this to create discrete capacitors with more capacitance!

You might also be able to get discrete capacitors with a higher value that will fit onto the board, depending on the actual input and output voltages you'll be using.

Check what parts are available in the 2012/0805 size (or 3216/1206 size, if you're willing to jam them in). We recommend that you stick with types having an X5R, X6S or X7R dielectric.

For example, 2.2µF 50V X5R capacitors are available in 2012/0805 size, if you can't fit a 1µF external ceramic bypass capacitor on your host board.

We've also built some variants with larger 1206 (3216 metric) sized input and output capacitors; you can see these in the photos.

On the other hand, if your design can tolerate some ripple at the output, then you may be able to reduce the output capacitance below the recommended value.

Just be careful to check that this doesn't affect stability under the range of load conditions the *Regulator* will experience.

When fitting the *Regulator* to your PCB, keep in mind that there are bare component leads on the back of the *Regulator* PCB which may short against (for example) the existing 78xx mounting hole. Some insulating tape (eg, polyimide) applied to the PCB should be sufficient to avoid problems here.

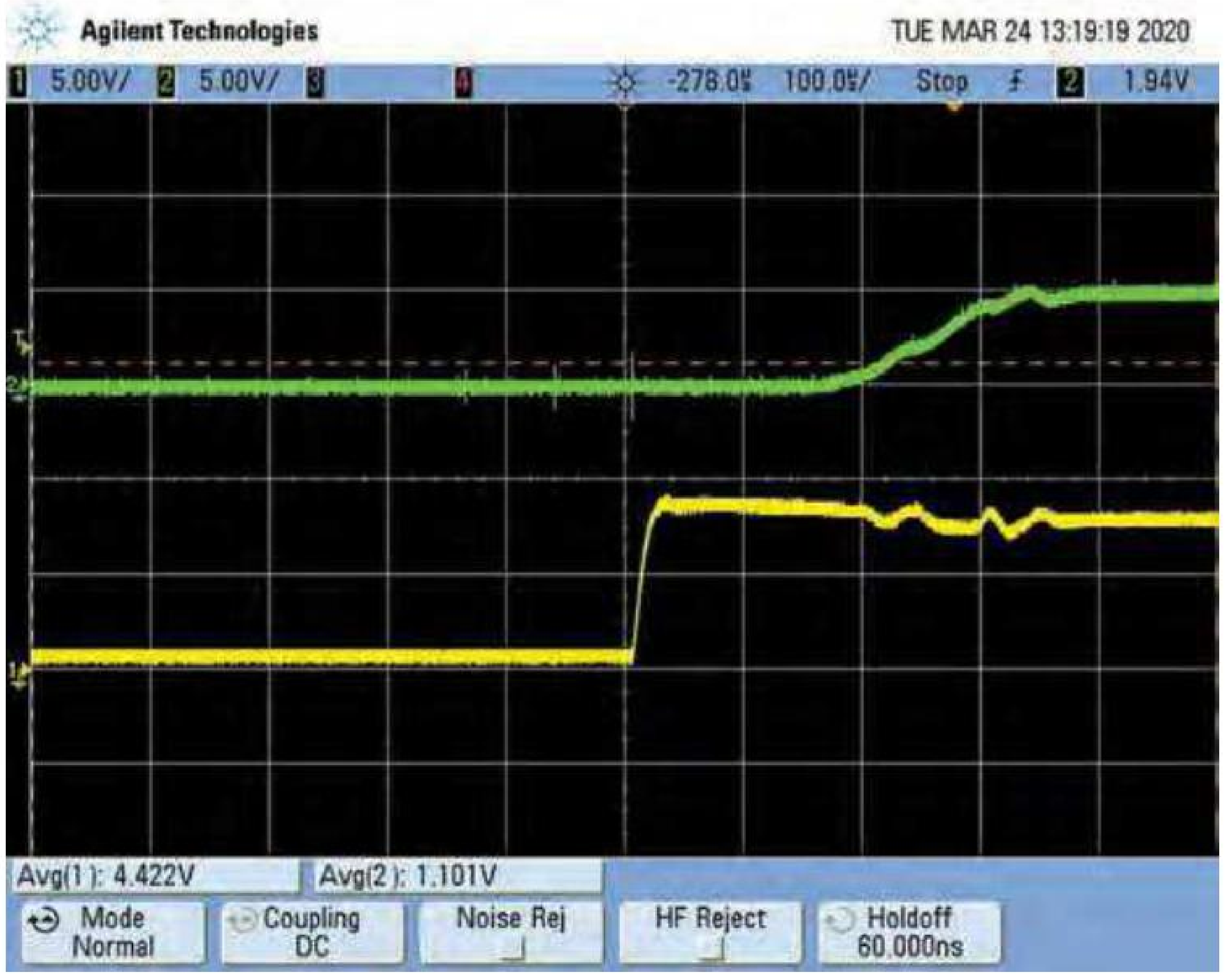
Parts list – '78xx'

1 double-sided PCB coded 18105201, 15 x 10 x 0.6mm available from the PE PCB Service
1 3-pin right-angle header, 2.54mm pitch (or straight header, depending on application) (CON1)
1 22µH 6mm x 6mm 1.1A inductor* (eg, BOURNS SRN6028-220M)
1 MCP16311 switchmode IC, MSOP-8 package (Digi-key, Mouser)

Capacitors (all X7R SMD ceramics, size 2012/0805)
3 1µF 50V^ *(code 105)*
1 100nF 50V *(code 104)*

Resistors (all 1% SMD size 2012/0805)
1 52.3kΩ (R1)* *(code 5232)*
1 10kΩ *(code 1002)*

** parts for 5V output; see Table 1 for other voltages*
^ increase to 2.2µF if an external low-ESR input bypass capacitor of at least 1µF is not possible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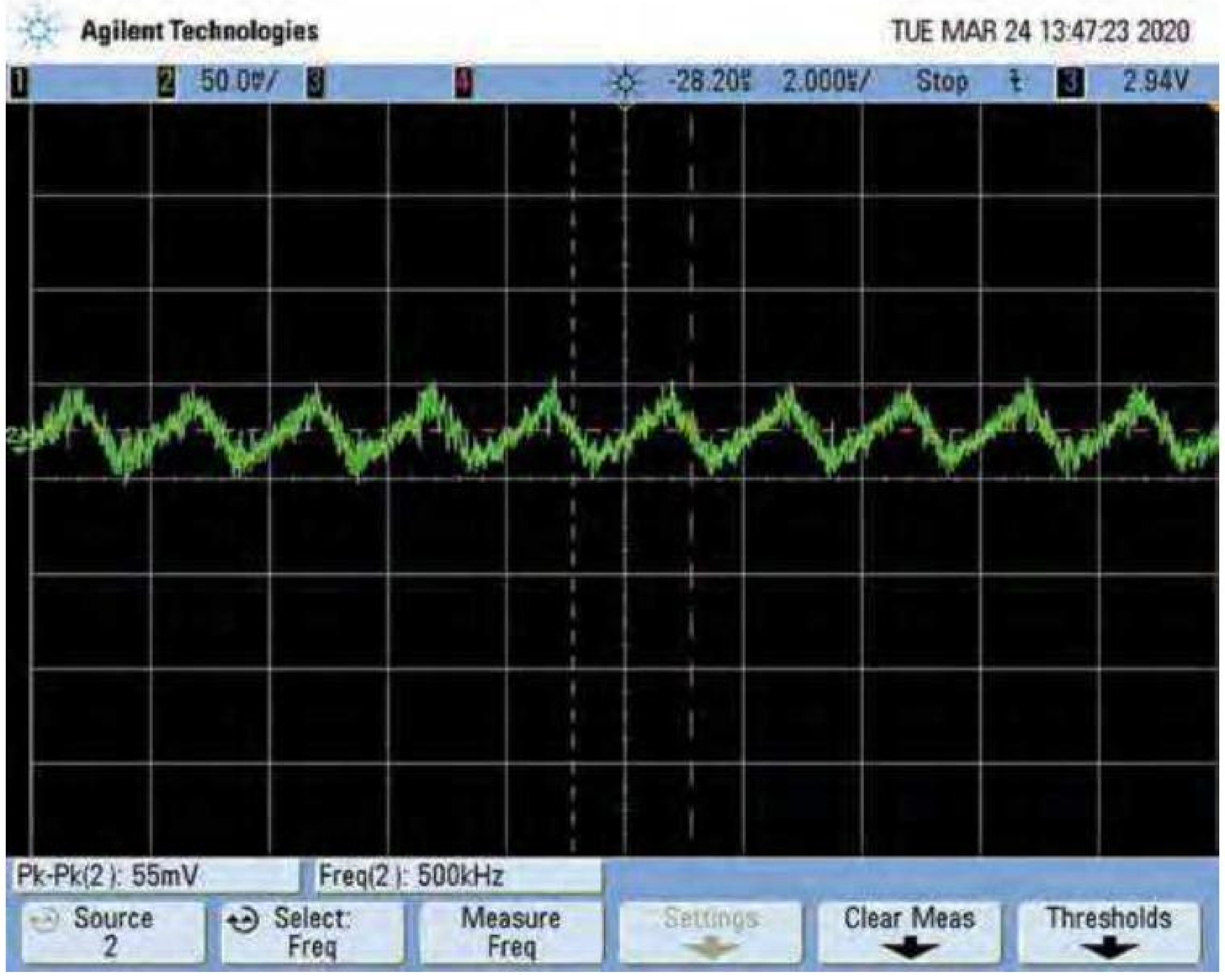
1 5.00V/ 2 5.00V/ 3 4
-278.0ꟷs 100.0ꟷs/ Stop ꟷ 2 1.94V
Avg(1): 4.422V
Avg(2): 1.101V
Mode Normal
Coupling DC
Noise Rej
HF Reject
Holdoff 60.000ns

Scope1: this shows the response of the *Regulator* to having 8V applied with an 8Ω load (625mA). Its startup time is limited mostly by having to charge the output capacitance, which would be the case for most regulator circuits.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1 2 50.0ꟷ/ 3 4
-28.20ꟷs 2.000ꟷs/ Stop 3 2.94V
Pk-Pk(2): 55mV
Freq(2): 500kHz
Source 2
Select: Freq
Measure Freq
Settings
Clear Meas
Thresholds

Scope2: same test conditions as Scope1, we've zoomed into the output waveform after it has had time to stabilise to show the output ripple. We see around 50mV of ripple at the MCP16311's 500kHz PWM frequency; more output filter capacitance would reduce this. This ripple is the main downside of using a switchmode regulator.

Under low load conditions, thermal dissipation will be quite low, so you could probably even seal the entire part in heatshrink tubing, although we haven't tested this.

Alternatively, if you have space, extend the headers pins of CON1 so that there is clearance between the *Regulator* PCB and the PCB underneath. If your design is subject to vibration, some neutral-cure silicone sealant between the two will reduce mechanical fatigue.

If you are using the right-angle mounting arrangement, then you will also lose the option to mechanically secure the *Regulator* PCB because it lacks a mounting hole. You should also ensure clearance between the *Regulator* PCB and any case parts that might short against the components on the *Regulator* PCB.

Again, some tape and sealant may be required to maintain clearance and insulation. If you have space, the right-angle connector (CON1) can be mounted at the front (rather than the back) of the PCB. This will increase the clearance behind it.

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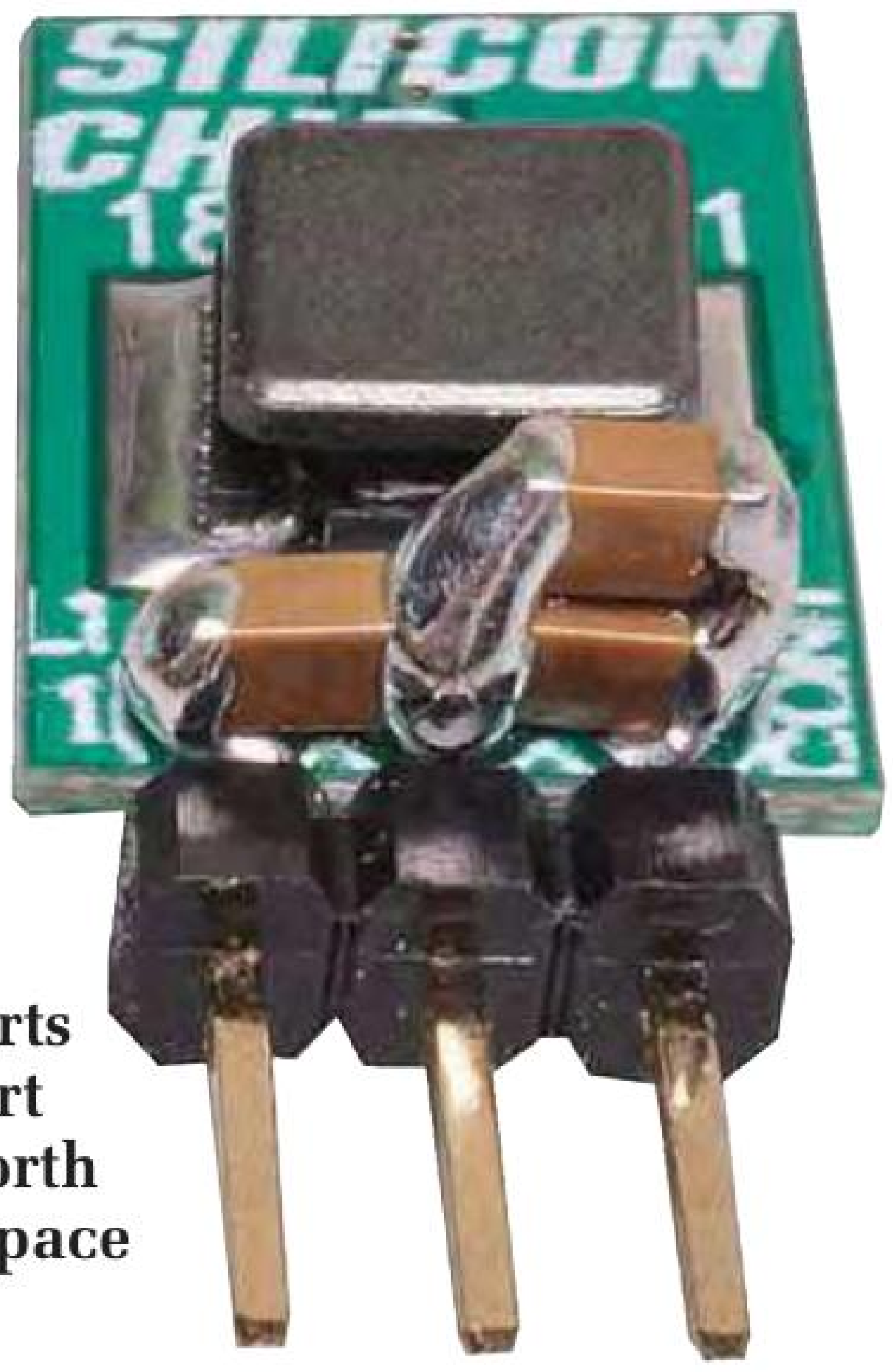
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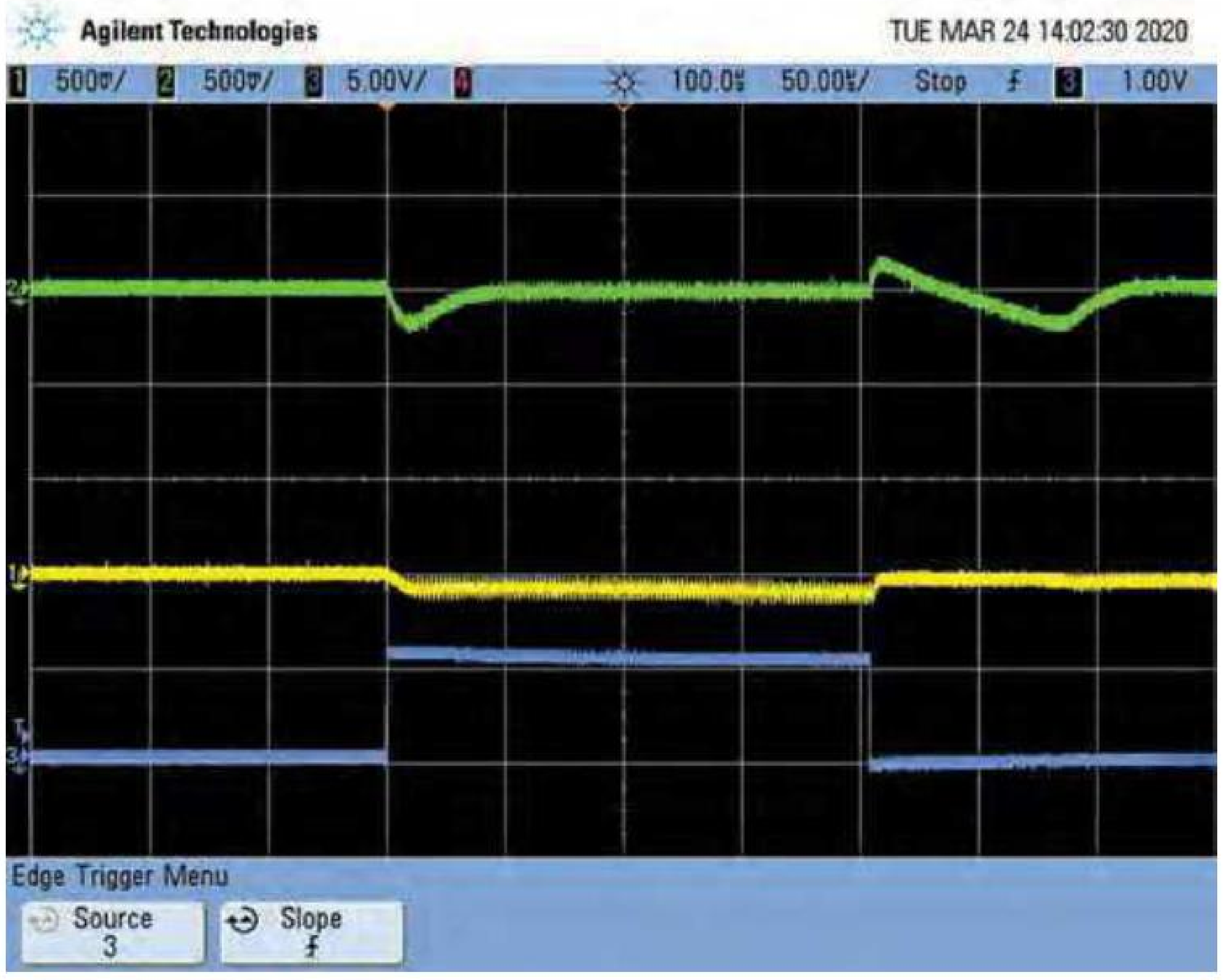
For some variants, we squeezed in slightly larger 3216/1206-sized capacitors across the input and output pins. It's generally easier to get these larger-valued or higher-rated parts in the larger part sizes, so it is worth considering if space is not critical.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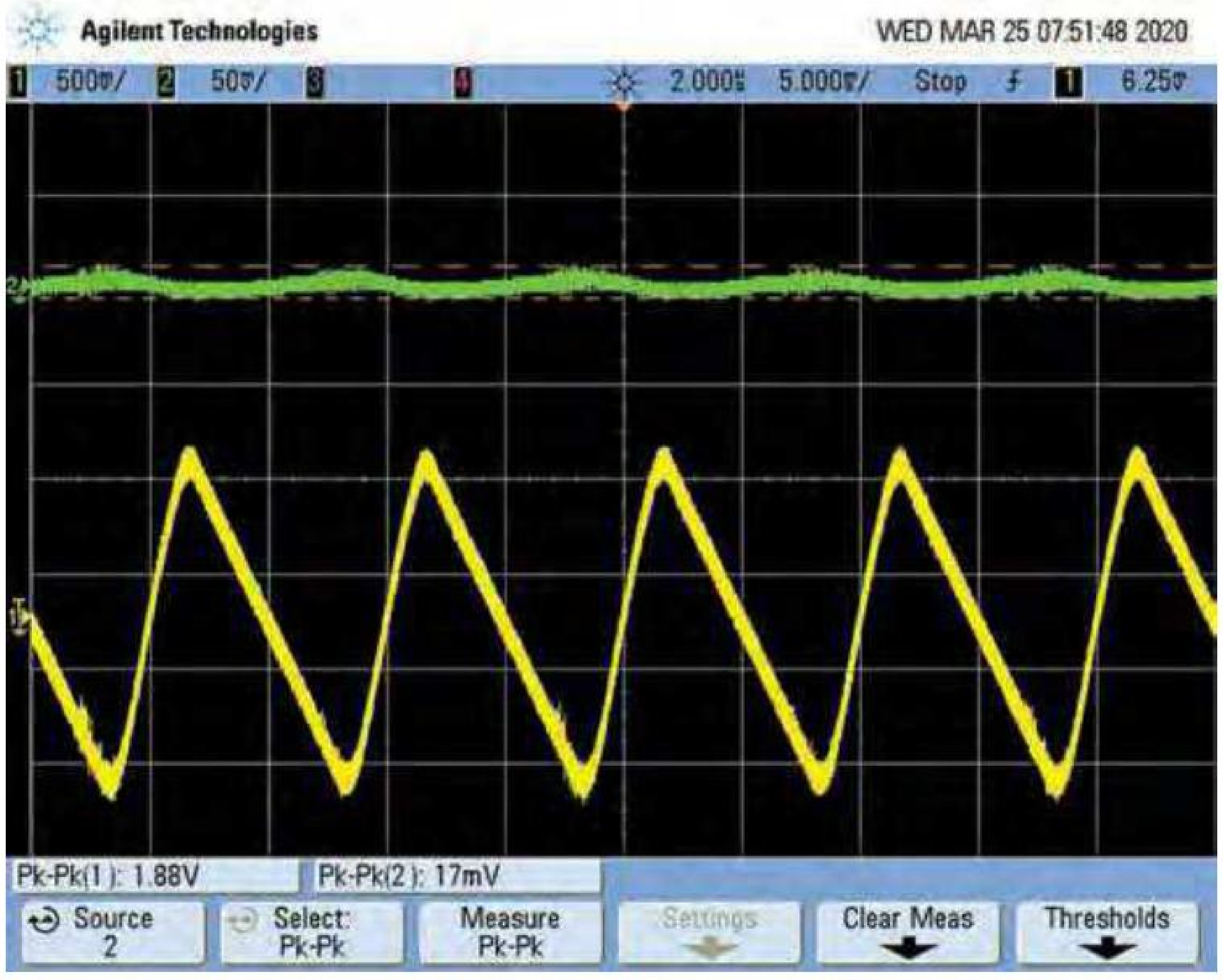
1 500ꟷ/ 2 500ꟷ/ 3 5.00V/ 4
100.0ꟷs 50.00ꟷs/ Stop ꟷ 3 1.00V
Edge Trigger Menu
Source 3
Slope

Scope3: here we connected a 68Ω load to the *Regulator* and switched a second 8Ω load in and out using a MOSFET (gate voltage in blue, the yellow trace is the supply voltage). Thus the output current jumps from 75mA to 700mA and back. The green trace shows the output voltage, which in all cases stays within 200mV of the setpoint. More output capacitance would stabilise this further.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1 500ꟷ/ 2 50ꟷ/ 3 4
2.000ꟷs 5.000ꟷs/ Stop 1 6.25ꟷ
Pk-Pk(1): 1.88V
Pk-Pk(2): 17mV
Source 2
Select: Pk-Pk
Measure Pk-Pk
Settings
Clear Meas
Thresholds

Scope4: the same 8Ω load as before but with the input supply being fed from an AC transformer and bridge rectifier with a 1000µF filter capacitor. Around 2V of ripple (at 100Hz) from the supply produces less than 20mV of ripple at the *Regulator's* output, an attenuation of around 100 times.

Fluke/Philips PM3092 Oscilloscope
2+2 Channel 200MHz Delay TB,
Autoset etc – £250

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LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£400
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£400
IFR 2025	Signal Generator 9kHz – 2.51GHz Opt 04/11	£900
IFR 2948B	Communication Service Monitor Opts 03/25 Avionics	POA
IFR 6843	Microwave Systems Analyser 10MHz – 20GHz	POA
R&S APN62	Syn Function Generator 1Hz – 260kHz	£295
Agilent 8712ET	RF Network Analyser 300kHz – 1300MHz	POA
HP8903A/B	Audio Analyser	£750 – £950
HP8757D	Scaler Network Analyser	POA
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£400
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHz – 20GHz	£2,000
HP83630A	Synthesised Sweeper 10MHz – 26.5 GHz	POA
HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10µW	£75
HP8560E	Spectrum Analyser Synthesised 30Hz – 2.9GHz	£1,750
HP8563A	Spectrum Analyser Synthesised 9kHz – 22GHz	£2,250
HP8566B	Spectrum Analsyer 100Hz – 22GHz	£1,200
HP8662A	RF Generator 10kHz – 1280MHz	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
Marconi 2024	Synthesised Signal Generator 9kHz – 2.4GHz	£800
Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
Marconi 2023A	Signal Generator 9kHz – 1.2GHz	£700
Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHz	£295
Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 2955B	Radio Communications Test Set	£800
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHz – 20GHz	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B	Power Meter with 6910 sensor	£295
Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
Tektronix TDS3032	Oscilloscope 300MHz 2.5GS/s	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHz 1.25GS/s	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHz 100MS/s	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHz	£600
Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell AP100-90	Power Supply 100V 90A	£900
Farnell LF1	Sine/Sq Oscillator 10Hz – 1MHz	£45
Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
Racal 9300B	As 9300	£75
Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

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KickStart

by Mike Tooley

Part 4: Introducing the Arduino Pro Mini

Our occasional *KickStart* series aims to show readers how to use readily available low-cost components and devices to solve a wide range of common problems in the shortest possible time. Each of the examples and projects can be completed in no more than a couple of hours using off-the-shelf parts. As well as briefly explaining the underlying principles and technology used, the series will provide you with a variety of representative solutions and examples along with just enough information to be able to adapt and extend them for their own use.

This fourth instalment shows you how to make use of the diminutive Arduino Pro Mini and, in keeping with the *KickStart* philosophy, we've provided sufficient information for you to be able to start making use of this tiny microcontroller in your own projects.

The Arduino has undoubtedly become immensely popular with *PE* readers because it can provide a highly effective solution to a wide range of problems at minimal cost. To cater for differing requirements, several versions of the Arduino have become available, making it possible to integrate the microcontroller into systems of virtually any size.

What's on the board?

The most popular Arduino version is undoubtedly the Uno, but for smaller applications, particularly where there is no need for a resident USB interface, this can be overkill. The Arduino Pro Mini puts this right by providing an attractive alternative in a tiny postage-stamp-sized package. Like its big brother (see Fig.4.1), the Pro Mini contains virtually everything that you need to implement a complete microcontroller system. The only additional items are a power source and a means of connecting a programming device via a serial interface and a USB cable.

The Pro Mini will operate quite happily from nothing more than a 3.7V or 9V battery, making it ideal for use in stand-alone applications where there's no mains supply available. Alternatively, the Uno can derive its power from an external DC source of between 5V and 12V, or via an external USB adapter and a powered USB port.

The Pro Mini provides a total of 14 digital input/output lines, together with six analogue inputs. Where necessary, signals on six of the 14 digital I/O lines can make use of pulse-width modulation (PWM) to effectively generate analogue outputs. The Pro Mini's technical specification is shown in Table 4.1.

ATmega328P processor

The Pro Mini is based on the same ATmega328P processor as the Arduino Uno, and this ensures there is a high degree of software and hardware compatibility. The processor has 32kB of Flash memory used for storing program code (of which 2kB bytes is reserved for bootloader code). The Pro Mini's chip

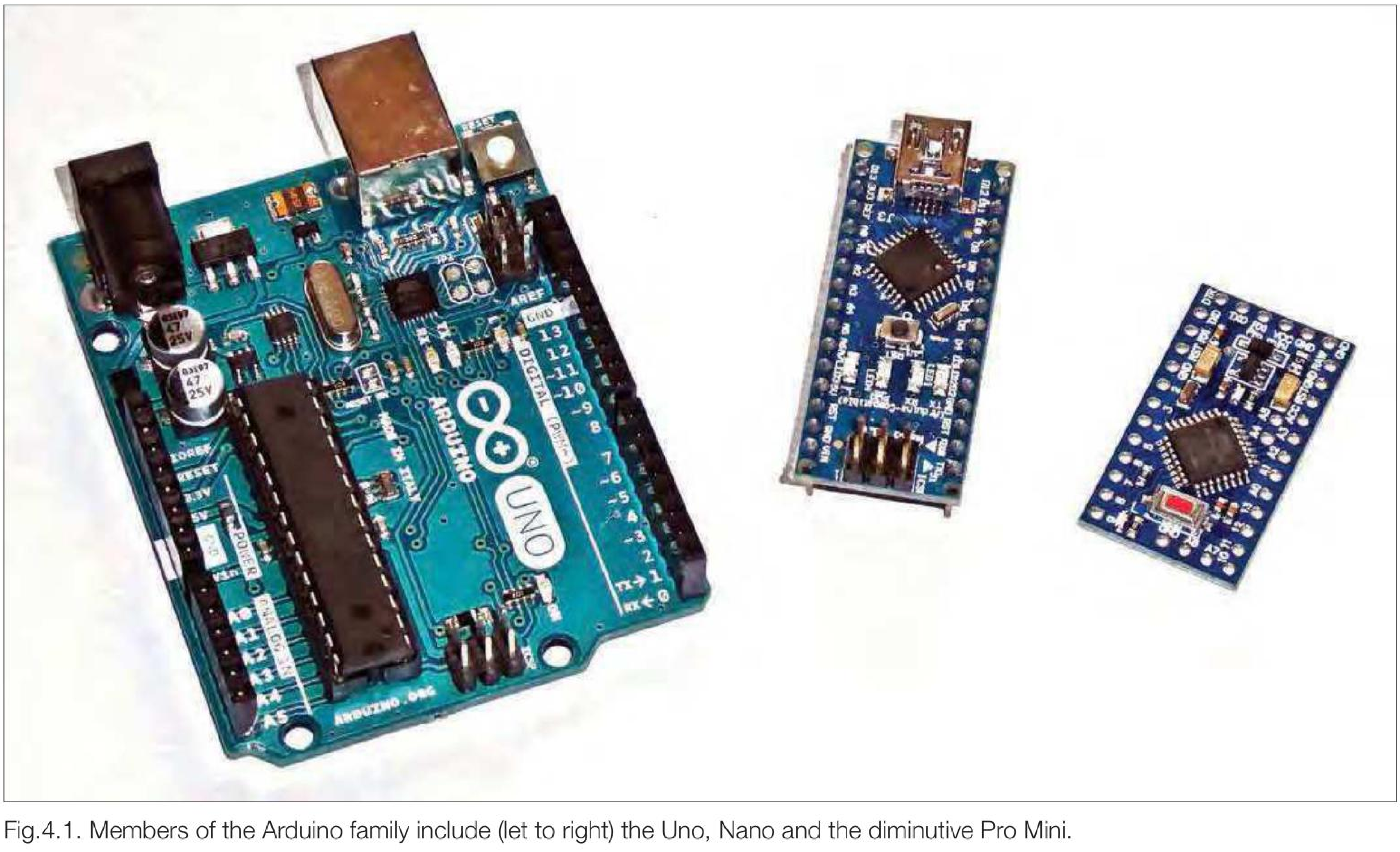

Fig.4.1. Members of the Arduino family include (let to right) the Uno, Nano and the diminutive Pro Mini.

Table 4.1 Technical specifications for the Arduino Pro Mini

Feature	Specification	Notes
Processor	ATmega328P	This is the same processor that is currently fitted to the Arduino Uno
Clock speed	8MHz or 16MHz	The 3.3V has an 8MHz clock, while the 5V version operates at 16MHz
Flash memory	32kB	2kB bytes used for the bootloader
Static RAM (SRAM)	2kB	Early versions had 1kB
EEPROM	1kB	Early versions had 512 bytes
Supply voltage (V_{CC})	3.3V or 5V depending on version	
Raw input voltage (pre-regulated)	3.35V to 12V for the 3.3V version; 7V to 12V for the 5V version	Please note the RAW power input needs 50mV headroom for the 3.3V version (and 2V for the 5V version).
Digital I/O pins	14	Six digital I/O pins can be used for PWM with 8-bit resolution
Analogue input pins	6	
Maximum output current (per pin)	40mA	150mA maximum total output current
Absolute maximum current	200mA	
External interrupts	2	Inputs from external hardware
Operating temperature range	−40°C to +105°C	
Dimensions	18 × 33mm	
Weight	Less than 2g	

also has 2kB of static random-access memory (SRAM) and 1kB of electrically erasable programmable read-only memory (EEPROM).

The ATmega328 incorporates two 8-bit timer/counters with separate pre-scaler and compare mode, and one 16-bit timer/counter with a separate pre-scaler. The chip incorporates six pulse-width modulated (PWM) channels available from a subset of digital I/O pins. With appropriate signal conditioning the PWM outputs can be used to generate quasi-analogue output voltages. The processor also incorporates a six-channel, 10-bit analogue-to-digital converter (ADC) and incorporates a variety of communications ports including a programmable serial USART, an SPI serial interface and a byte-oriented 2-wire serial I^{2}C-compatible interface. As a bonus, the chip also incorporates a programmable watchdog timer.

The ATmega328 has a total of 23 input/output (I/O) lines. Before we expand on what these can do, it is important to be aware that ATmega328 I/O lines can be software configured for different functions. As an example, the port line labelled PB3 (ie, Port B, bit 3) provides Master data output and Slave data input when the chip is configured for use with the Serial Peripheral Interface (SPI) bus. Alternatively, it can be configured to provide an external output for the PWM timer function or as an external interrupt source. This may sound a little complicated at first, but it does make a significant contribution to the chip's wide applicability and immense versatility.

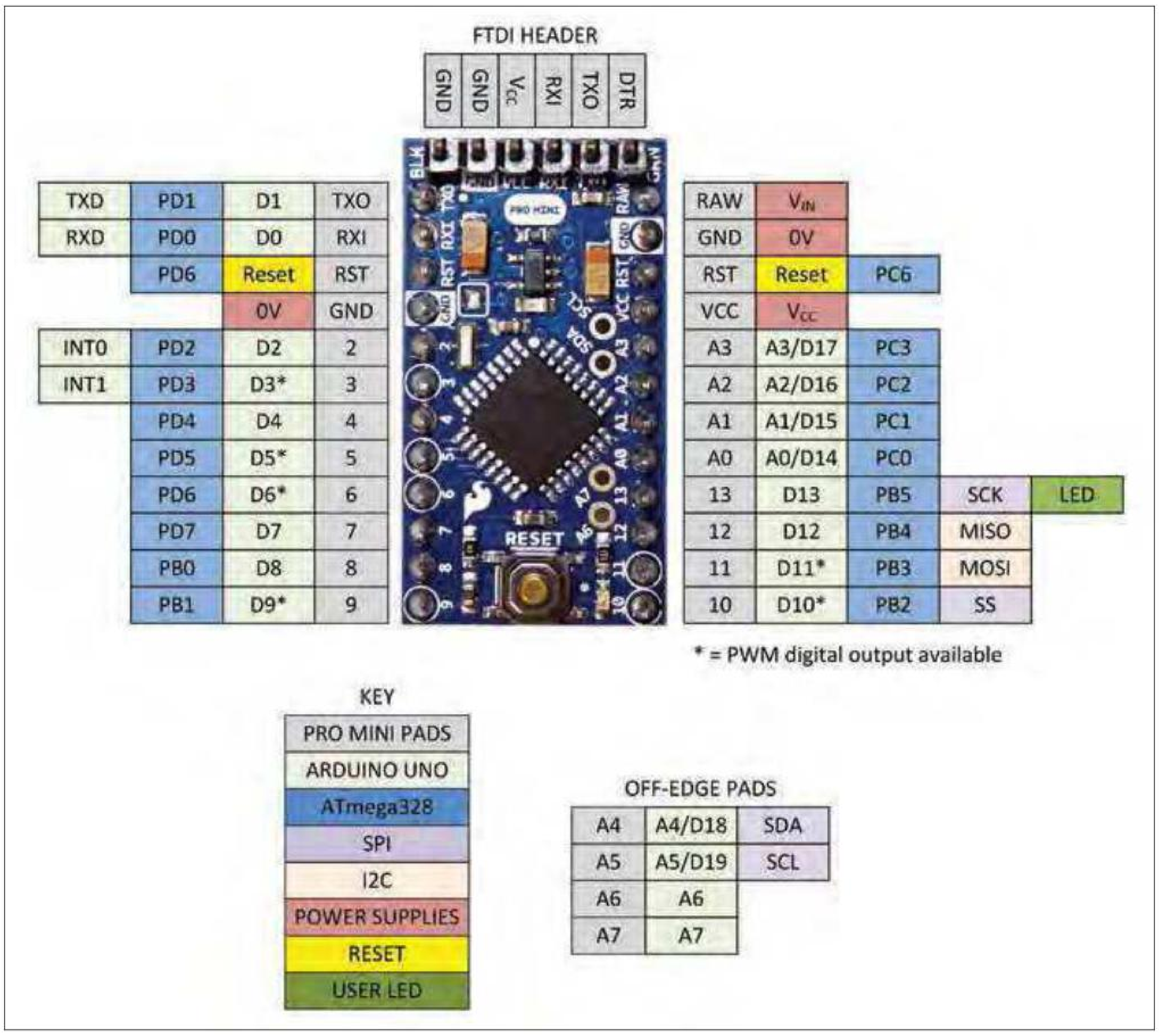
FTDI HEADER
GND GND Vcc RXI TXO DTR
TXD PD1 D1 TXO
RXD PD0 D0 RXI
PD6 Reset RST
0V GND
INT0 PD2 D2 2
INT1 PD3 D3* 3
PD4 D4 4
PD5 D5* 5
PD6 D6* 6
PD7 D7 7
PB0 D8 8
PB1 D9* 9
RAW V_IN
GND 0V
RST Reset PC6
VCC Vcc
A3 A3/D17 PC3
A2 A2/D16 PC2
A1 A1/D15 PC1
A0 A0/D14 PC0
13 D13 PB5 SCK LED
12 D12 PB4 MISO
11 D11* PB3 MOSI
10 D10* PB2 SS
* = PWM digital output available
KEY
PRO MINI PADS
ARDUINO UNO
ATmega328
SPI
I2C
POWER SUPPLIES
RESET
USER LED
OFF-EDGE PADS
A4 A4/D18 SDA
A5 A5/D19 SCL
A6 A6
A7 A7
PRO MINI
RESET

Fig.4.2. Pro Mini board layout showing main components and connectors.

Pro Mini Port B

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high-sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running. Depending on the clock selection fuse settings, PB6 can be used as input to the inverting oscillator amplifier or input to the internal clock operating circuit. In the same manner, PB7 can be used as output from the inverting oscillator amplifier. If the internally calibrated RC oscillator is used as the chip's clock source, PB6 and PB7 are used as inputs for the second asynchronous timer/counter.

Pro Mini Port C

Port C is a 7-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The PC0 to PC5 output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running. PC6 can be fuse programmed for use as an I/O pin or to function as a RESET pin. In the latter case, a low level held briefly on this pin generates a reset.

Pro Mini Port D

Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high-sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Using the Pro Mini I/O

The I/O features and capability are very similar to those offered from a standard Arduino Uno, but there are some notable differences in relation to the pinout configuration and headers, as shown in Fig.4.2.

Each of the 14 digital pins (see Fig.4.2) on the Pro Mini can be configured as a digital input or output by using the appropriate C functions:

```
pinMode()
digitalWrite()
digitalRead()
```

The digital I/O lines operate at standard TTL-compatible levels and each of the I/O pins can source or sink a maximum current of 40mA. Internal pull-up resistors of around 20 to 50kΩ can be selected where necessary. Note that the internal pull-up facility is disabled by default. As previously mentioned, it is important to be aware that many of the Pro Mini's digital I/O lines also have specialised functions.

Serial I/O pins TXO and RXI

These two pins can be used for serial communication. The same pins are also made available on the six-pin header to which an FTDI serial-to-USB interface can be attached in order to facilitate downloading and debugging of code.

Interrupt pins 2 and 3

These two pins are available for use with external interrupts. They can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. The `attachInterrupt()` function can be used to configure the interrupt feature.

Pulse width modulation (PWM) using pins 3, 5, 6, 9, 10, and 11

These six lines can be used to provide outputs that are pulse-width modulated (PWM). This feature can be used to provide quasi-analogue outputs using the `analogWrite()` function.

Serial SPI communication using pins 10, 11, 12 and 13

These four pins support SPI serial communication by providing SS, MOSI, MISO and SCK signals respectively.

User LED pin 13

As well as the red LED power indicator, a separate user LED is available at pin 13. When the pin is taken HIGH, the LED will be on and when LOW the LED will be off. The user LED provides a handy way of visually testing simple I/O code routines without the need to connect an external indicator.

Analogue I/O

In addition to the 14 digital I/O lines, the Uno has six analogue inputs, each of which provide 10 bits of resolution (ie, $2^{10} = 1024$ different values over a range extending from 0V to $+V_{CC}$).

I^{2}C communication using pins 27 and 28

Analogue I/O port lines 4 and 5 (pins 27 and 28 respectively) can be used to provide access to the SDA and SCL signals respectively, which facilitate the two-wire interface (TWI or I^{2}C). Note that these two signals are available on off-grid pads located away from the three main headers (see Fig.4.2).

Pro Mini Pinout

The Pro Mini's pinout connections are shown in Fig.4.2. For clarity we have colour coded the signal lines into different groups, as follows:

PRO MINI PADS (grey)

These correspond to the silk screen markings on the upper (component) side of the Pro Mini's PCB

ARDUINO UNO (light green)

These are the corresponding pin identifications for the standard version of the Arduino Uno.

ATmega328 (blue)

These are the processor's port designations

SPI (lilac)

These connections are for use with SPI (Serial Peripheral Interface) devices

I2C (pink)

These connections are used with 'two-wire' I^{2}C interface devices

POWER SUPPLIES (red)

These connections provide access to the internal and external supply rails as well as common 0V/Ground

RESET (yellow)

This is connected to the Pro Mini's reset line

USER LED (green)

This digital I/O line can be used to provide a simple 'user LED' indication.

It is worth noting that versions of the Pro Mini may have slightly different layouts and pin markings. This is particularly applicable to the location and marking of the four off-grid pads. The version shown in Fig.4.2 is, however, currently the most common.

Connecting to the Pro Mini

As with other members of the Arduino family, the Pro Mini's processor is supplied with bootloader code that will let you upload new code to it without the use of an external hardware programmer. This makes the process of developing and downloading code very

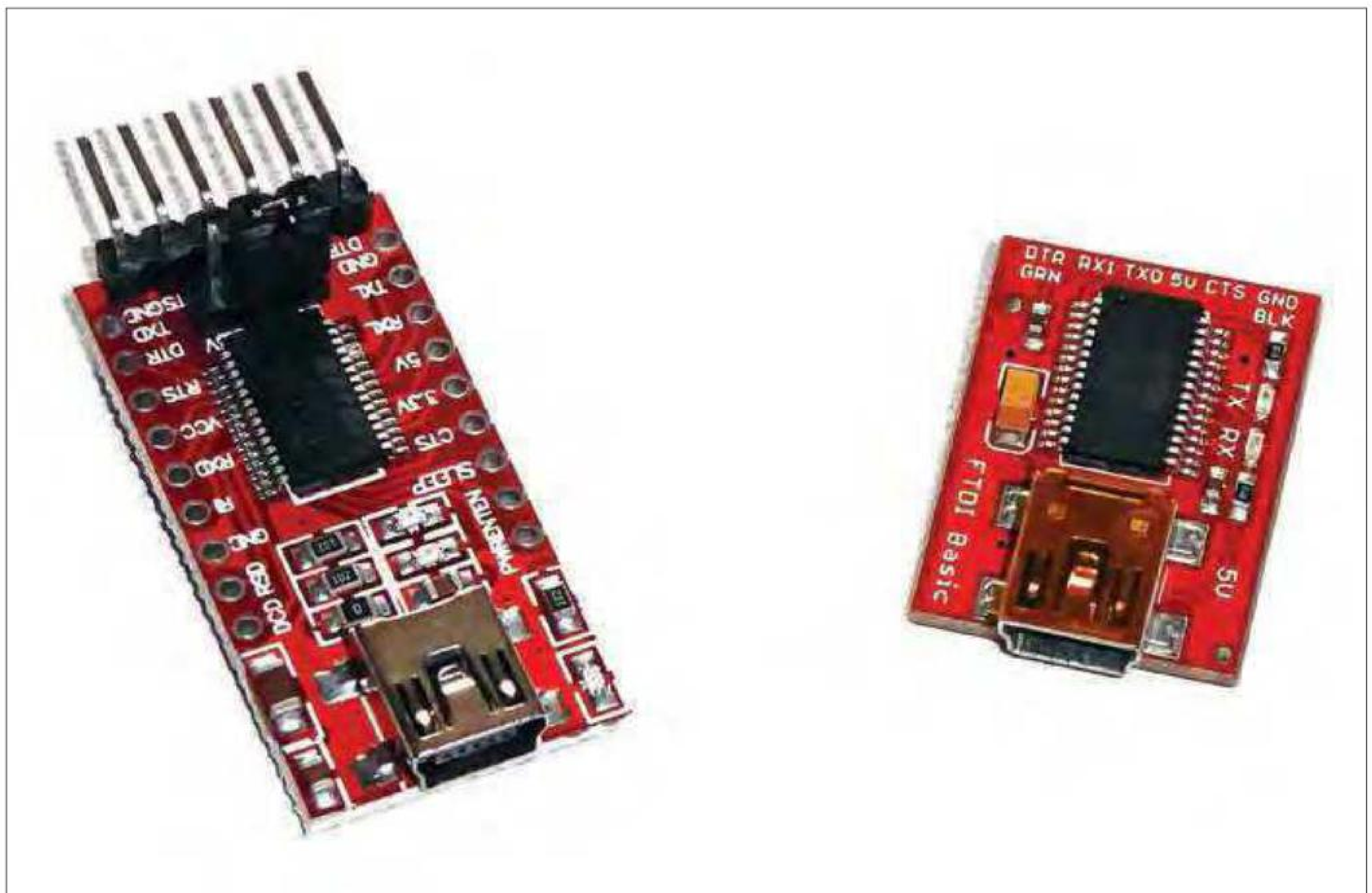

Fig.4.3. Two different serial FTDI interface boards for use with the Arduino Pro Mini.

simple and all you will require is the services of a serial USB interface that will connect to the Pro Mini's FTDI header (see Fig.4.2). Note, however, that different version of the Pro Mini may have a different FTDI header orientation (see Fig.4.3) and so, if you intend to mate the two directly with headers it is important to check before connecting the interface.

The process of establishing a connection via an FTDI serial adapter to a programming device such as a PC is as follows:

1. Connect the FTDI serial interface to the Pro Mini via the six-way header, ensuring that the connections are correctly made.
2. Connect the FTDI serial interface via a USB cable to the host PC.
3. Check that you have the correct virtual COM port (VCP) drivers installed for the FTDI interface. These may install automatically, or you may need to download them from the chip manufacturer (see *Going Further* below) if the virtual COM port is not recognised by your PC (the support documentation on the FTDI provides an *Installation Guide*, but we recommend that you opt to download the 'Setup' zipped file to a folder of your choice before extracting the files and running the executable to complete the installation.
4. Open the Arduino IDE on the host PC and select 'Tools' and then 'Board'. Scroll down the list of boards and select 'Arduino Pro Mini' from the Boards List Manager (*do not* just select 'Arduino Mini' – this will not work!)
5. Return to the IDE main menu and select 'Tools' and 'Port' and then select your newly enabled virtual COM port. If this does not appear in the list then repeat steps 2 and 3.
6. You should now have a working connection to the Pro Mini, so return to the IDE and select 'File', 'Examples' '01.Basics' and 'Blink' from the list of sample files. The file should then appear in the IDE's editing window together with a tab which indicates the default filename under which it will be stored and made available for future editing.
7. Now select 'Sketch' and 'Upload' to send the code to the Pro Mini. This will take a short time, after which a 'Done uploading' message will appear, informing you that the transfer has been made. The Pro Mini will then restart, and your efforts will be rewarded by a flashing 'user LED' connected to digital I/O line 13. You are now ready to create your own program code for downloading to the Pro Mini!

Listing 4.1 Code for the Pro Mini Frost Alert.

```
/*
     PE KickStart Frost Alert (Listing 4.1)
*/

// Assign LEDs to digital I/O lines
int redLED = 5;     // Red LED connected to DIO5
int amberLED = 6;   // Amber LED connected to DIO6
int greenLED = 7;   // Green LED connect to DIO7

// Assign analogue input
const int analogPin = 0; // Input to analog A0

// Set threshold levels
int freezing = 102; // At 0 deg.C appx. (change as required)
int warning = 110;  // At 4 deg.C appx. (change as required)

// Setting up
void setup() {

  // Initialize digital I/O pins outputs
  pinMode(redLED, OUTPUT);
  pinMode(amberLED, OUTPUT);
  pinMode(greenLED, OUTPUT);
}

// Loop forever
void loop() {
  int input = analogRead(analogPin);// Read the input
  Serial.println(input);
  if (input > warning) {
     green();
  }
  else if (input > freezing) {
     amber();
  }
  else red();
}

// LED indications
void red() {
  digitalWrite(redLED, HIGH);
  digitalWrite(amberLED, LOW);
  digitalWrite(greenLED, LOW);
}
void green() {
  digitalWrite(redLED, LOW);
  digitalWrite(amberLED, LOW);
  digitalWrite(greenLED, HIGH);
}
void amber() {
  digitalWrite(redLED, LOW);
  digitalWrite(amberLED, HIGH);
  delay(1000);
  digitalWrite(amberLED, LOW); // Flash the amber LED
  delay(1000);
  digitalWrite(greenLED, LOW);
}
```

A sample application

To show you just how easy the Pro Mini is to use and incorporate in your own designs, here is a simple example in the form of a *Frost Alert*. This handy device will warn you when the temperature has fallen to a low value where frost and ice are likely to be present. The device can be built using a Pro Mini and just seven other components, three resistors, three LEDs and one TMP36 temperature sensor and it can be put together in less than ten minutes! The complete circuit of the *Frost Alert* is shown in Fig.4.4.

The TMP36 temperature sensor is one of a family of three accurate, low-cost temperature sensors that provide analogue output voltages in response to temperature. The TMP36 is recommended for use over the temperature range −40°C to +125°C and it offers an accuracy better than ±2°C and typically ±1°C at +25°C. The output voltage is linearly proportional to the temperature measured in degrees Celsius, as illustrated by Fig.4.5.

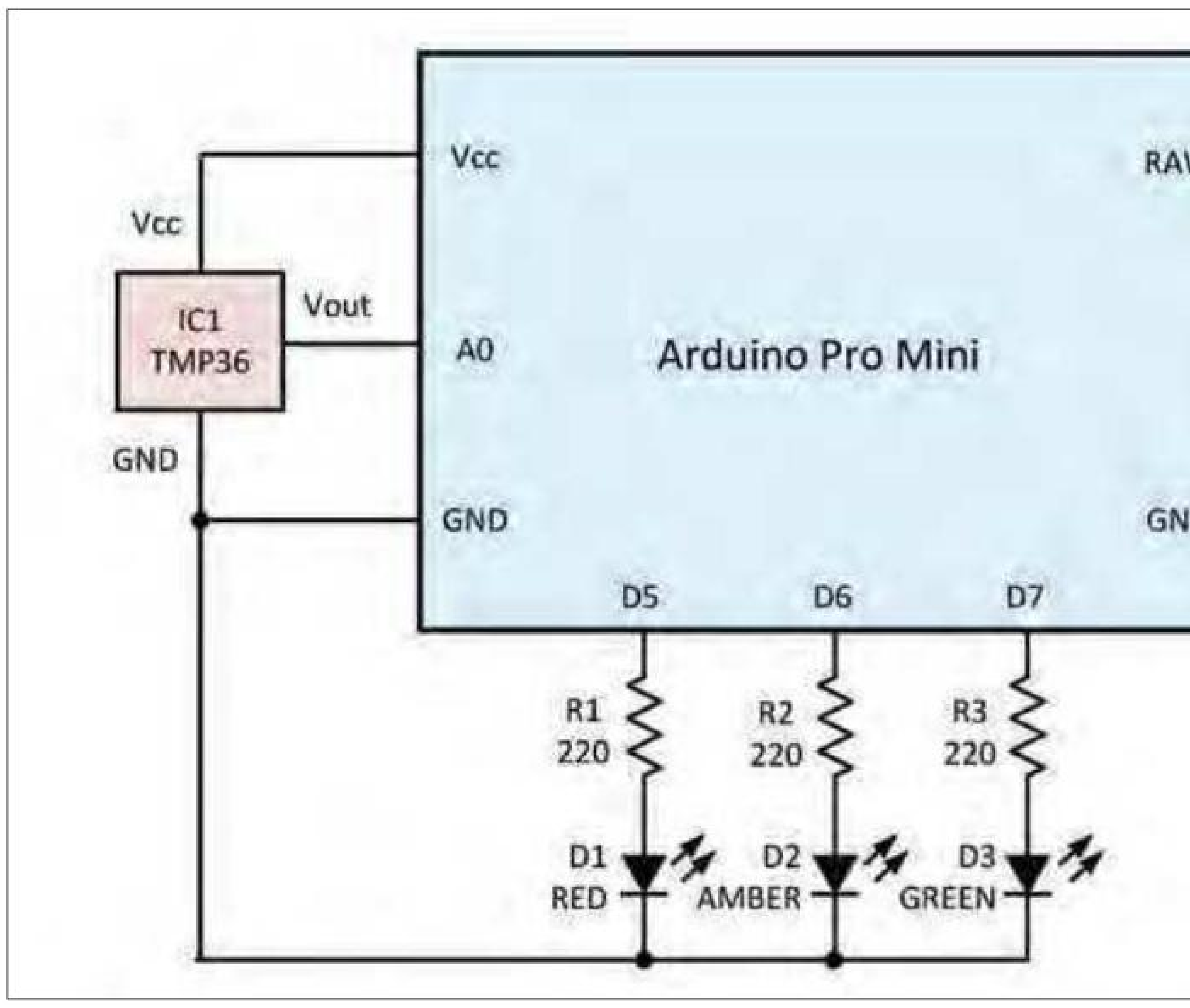

Fig.4.4. Circuit of the Pro Mini *Frost Alert*.

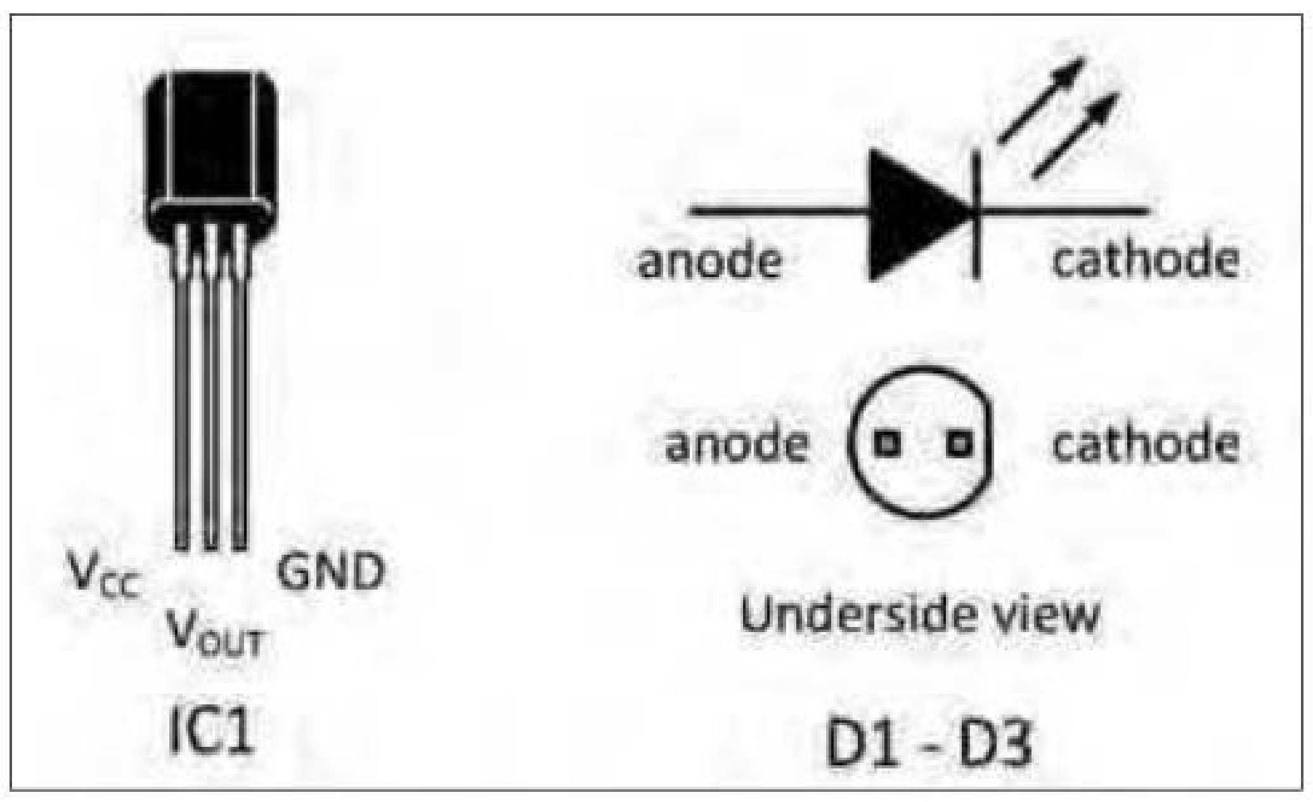

Fig.4.6. Semiconductor pin connections for the TMP36 temperature sensor.

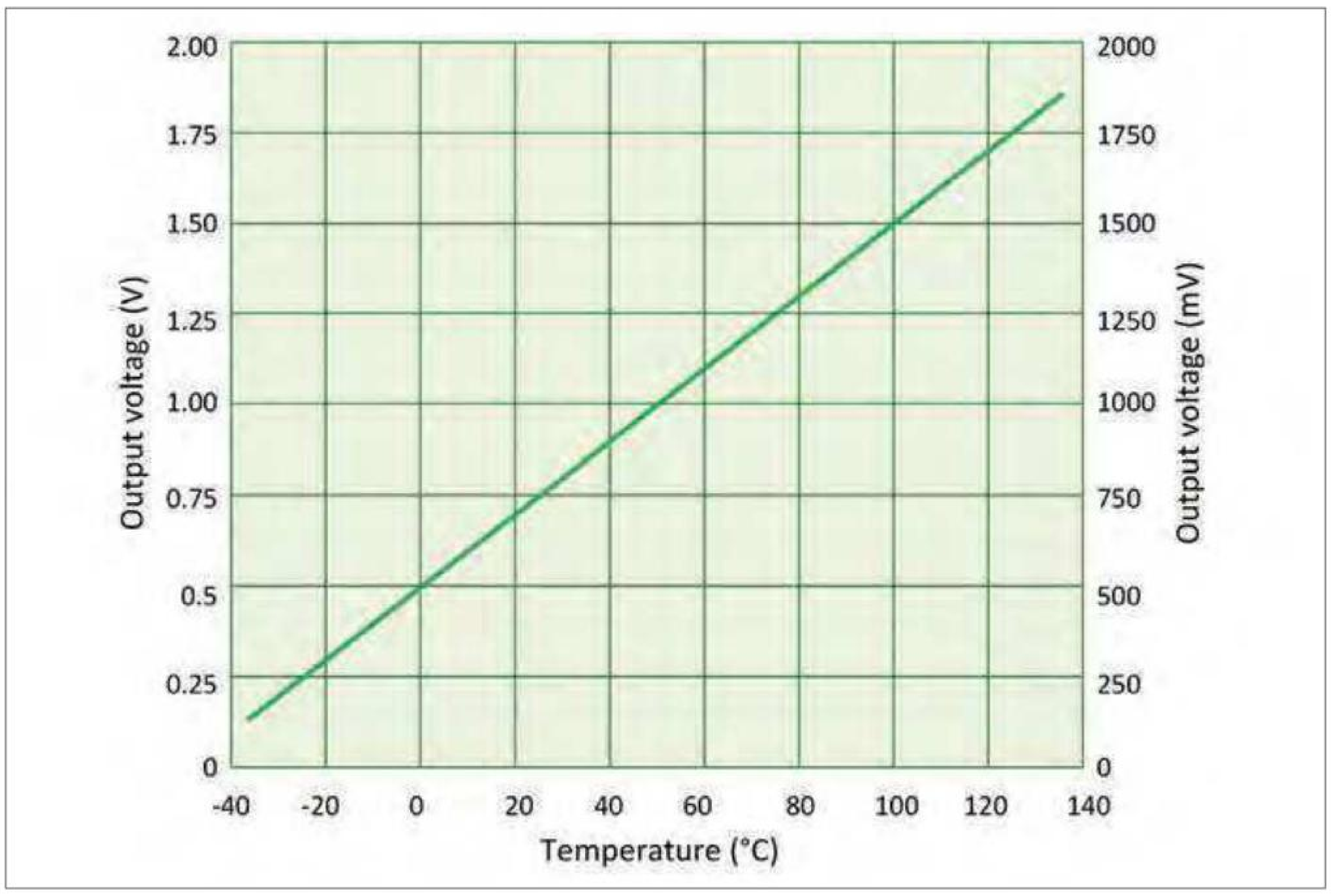

Fig.4.5. Characteristics of the TMP36 temperature sensor.

The TMP36 is intended for single-supply operation from 2.7V to 5.5V and is thus eminently suitable for operation from the Arduino's +3.3V or +5V supply. To avoid the risks associated with self-heating, the chip requires only a very small supply current (well below 50µA). In addition, a shut-down function is available to limit the residual supply current to less than 0.5µA. The TMP36 provides a nominal output voltage of 750mV output at +25°C, changing at the rate of +10mV/°C. At 0°C its output will be 500mV and, for example, at 4°C it will be 540mV. The interface to the Pro Mini's analogue port (see Fig.4.4) is extremely simple and no other components are required apart from the temperature sensor itself. The pin connections for IC1 and D1-D3 are shown in Fig.4.6.

The minimal code for the *Frost Alert* is shown in Listing 4.1 (this is also available for downloading from the *PE* website). As mentioned previously, before you can begin to enter code into the Pro Mini you will need to connect it to a PC that has a copy of the Arduino's integrated development environment (IDE) installed on it.

Table 4.2: Going Further with the Arduino Mini Pro

Topic	Source	Notes
Arduino Pro Mini	The Arduino Pro Mini is available from various suppliers, including HobbyTronics, Pimoroni, SparkFun, AZ-Delivery, and Adafruit. Several of these suppliers also have some useful downloadable tutorials.	When ordering, it is important to specify the 3.3V or 5V version (as required).
FTDI serial-to-USB interface	The FTDI Basic Breakout Board serial-to-USB interface drivers can be downloaded from: **www.ftdichip.com**	An installation guide is also available.
Arduino IDE	The Arduino IDE can be downloaded from: **www.arduino.cc/en/software**	Versions are available for Windows, Linux and macOS.
Arduino Uno	*Electronics Teach-In 8*. (available from Electron Publishing – see **http://bit.ly/pe-apr21-ks2-7**) provides a comprehensive guide to the Arduino. This popular series introduces hardware and software and also features a range of practical projects with different levels of complexity.	The *PE Direct Book Service* at **electronpublishing.com** has several other titles suitable for background reading on the Arduino family.
Sensors and interfacing	The author's book, *Electronic Circuits: Fundamentals and Applications* (5th Ed, 2020, Routledge 9780367421984) provides a general introduction to sensors and interfacing. The book also has a useful chapter on electronic applications and the Arduino.	
TMP36 temperature sensor	The TMP36 datasheet is available from: **www.analog.com/en/products/tmp36.html**	

This very simple application will give you a taste for what can be done with a Pro Mini. The *Frost Alert* is an obvious candidate for further development and makes a great basis for experimentation. It could be easily extended by adding a sounder to provide an audible warning (in addition to, or in place of D2). Alternatively, the design could be adapted for use as a thermostat for heating control in a greenhouse or conservatory. By replacing the temperature sensor with a light sensor (eg, an NORP12 and a 4.7kΩ series resistor) the device can be modified to warn of poor light levels or control lighting. One thing you can be certain of is that this postage stamp sized microcontroller can help in an immense variety of simple applications!

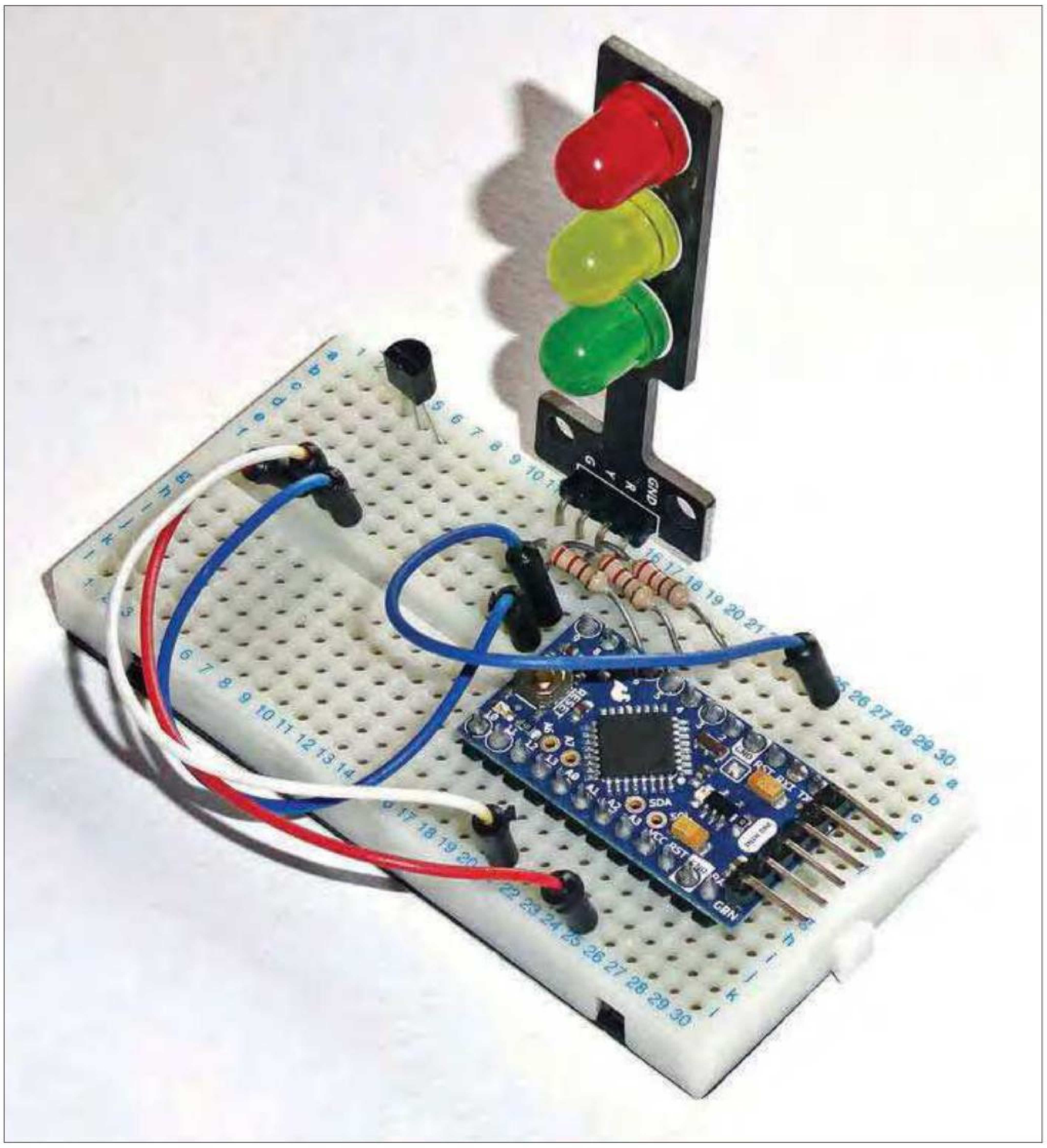

Fig.4.7. The completed prototype *Frost Alert*.

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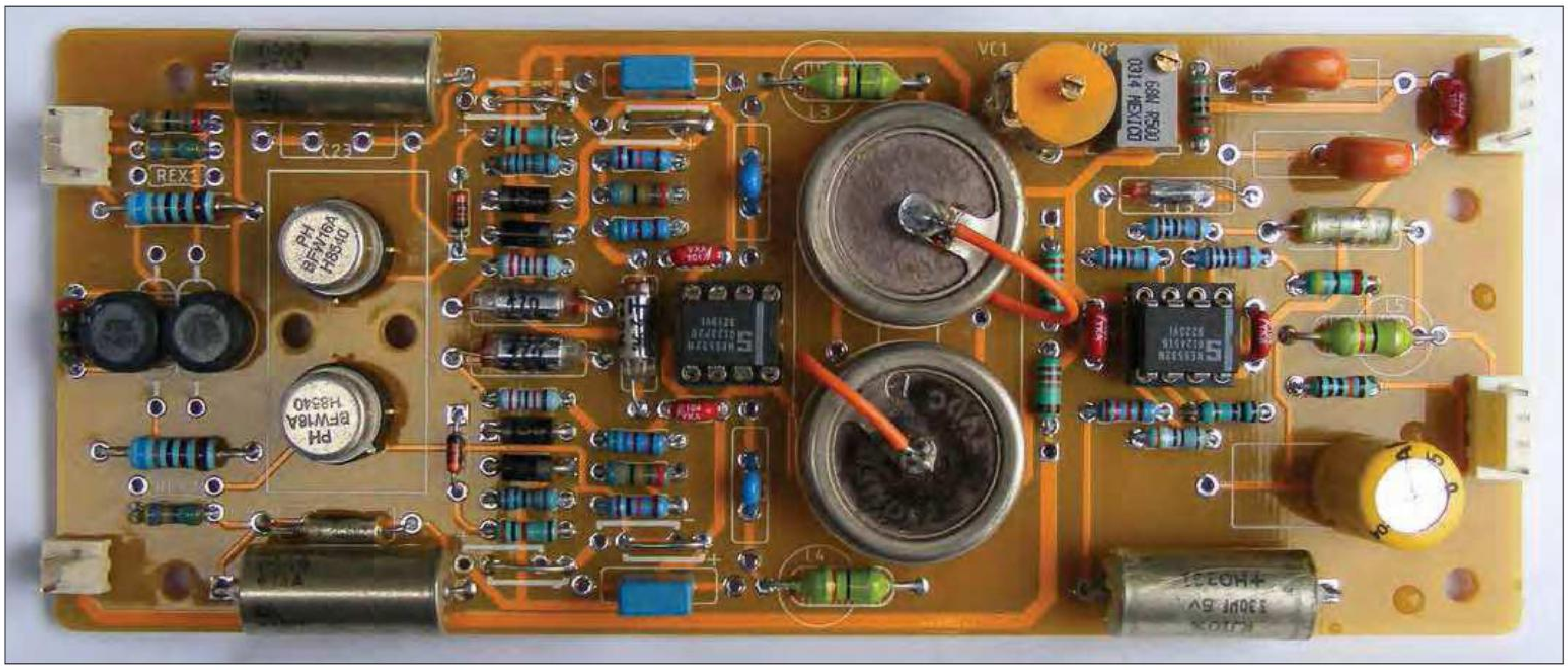
AUDIO OUT

By Jake Rothman

Microphone Preamplifier (for Vocoder) – Part 4



The *Microphone Preamplifier* board, as completed in last month's column.

Last month, we looked at building and testing the Microphone Preamplifier. This month, we conclude with some modifications and design options. A project like this is never truly 'finished' – there's always room for additions and improvements, but you have to draw line at some point!

Adding transformers

One preamplifier mod it's often worth doing in electrically noisy environments (such as near lighting rigs), is to add an input transformer to the already balanced input shown in Fig.14 (see *Part 2* in *Audio Out*, June 2021). This significantly increases the CMRR to top-class levels. Also, the CMRR of solid-state inputs is strictly limited to around 5V or whatever level causes the input amps to clip. A transformer, however, can tolerate around 100V common-mode voltage. This double-balancing technique was employed by S. Groner in his microphone-preamplifier in the March 2015 issue of the *Journal of the Acoustic Engineering Society* (*JAES*). A 600Ω 1:1 line-level transformer is much cheaper than a step-up microphone transformer. However, a mu-metal screening can to avoid hum pick-up would also be needed. These are readily available from Vigortronix in all sizes. Another bonus is that the phantom power could also then be fed via a centre-tap, rather than 6.8kΩ resistors.

A further reason transformers can sound better is because there is less voltage drop on the 48V microphone supply due to their lower series DC resistance of around 30Ω. The voltage to many microphones can drop to as low as 35V due to the 6.8kΩ resistors.

Output transformer

Output transformers offer the unique property of earth isolation, the floating output prevents earth loops however they are connected, even if one side of the balanced output is grounded. (This is the case when feeding unbalanced inputs.)

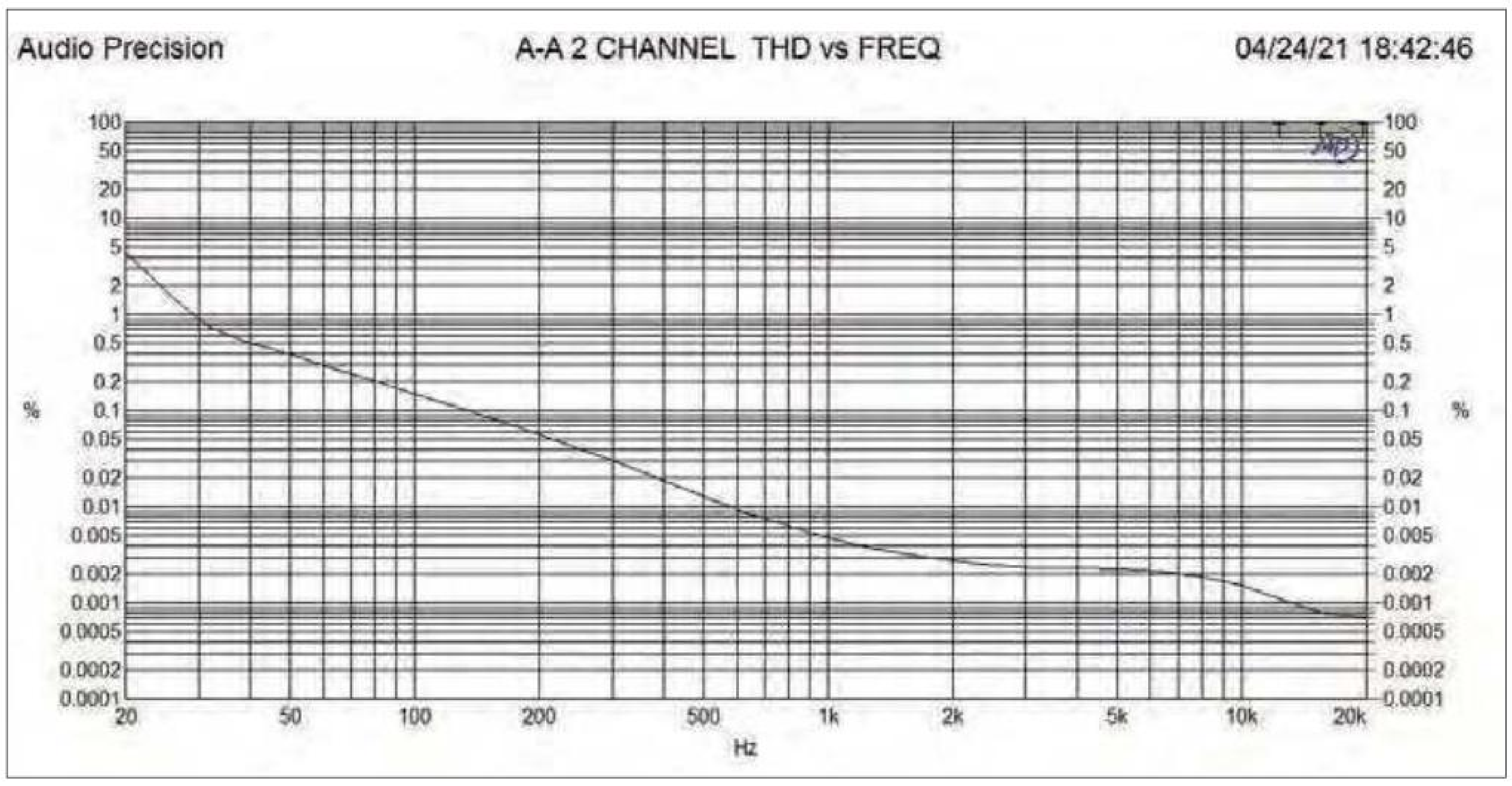


Fig.37. The distortion curve of the output transformer at 7V peak-to-peak feeding 600Ω. Note the typical rise at low frequencies. This is emphasised because the transformer is being slightly over-driven at this level.

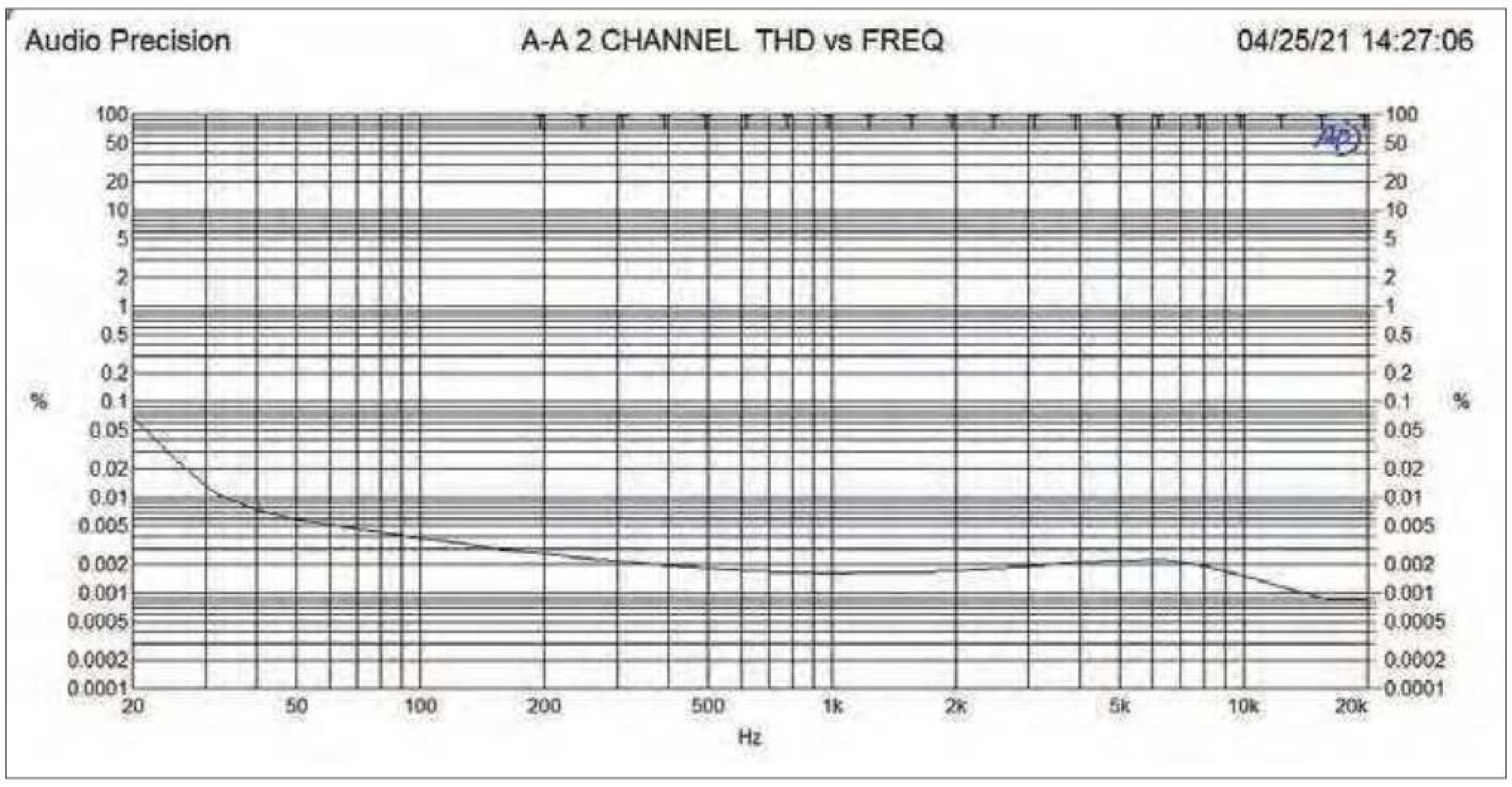


Fig.38. The effect of the negative-resistance distortion-reduction circuit (Fig.42). Same conditions as in Fig.37, but with an almost 10-times reduction in distortion.

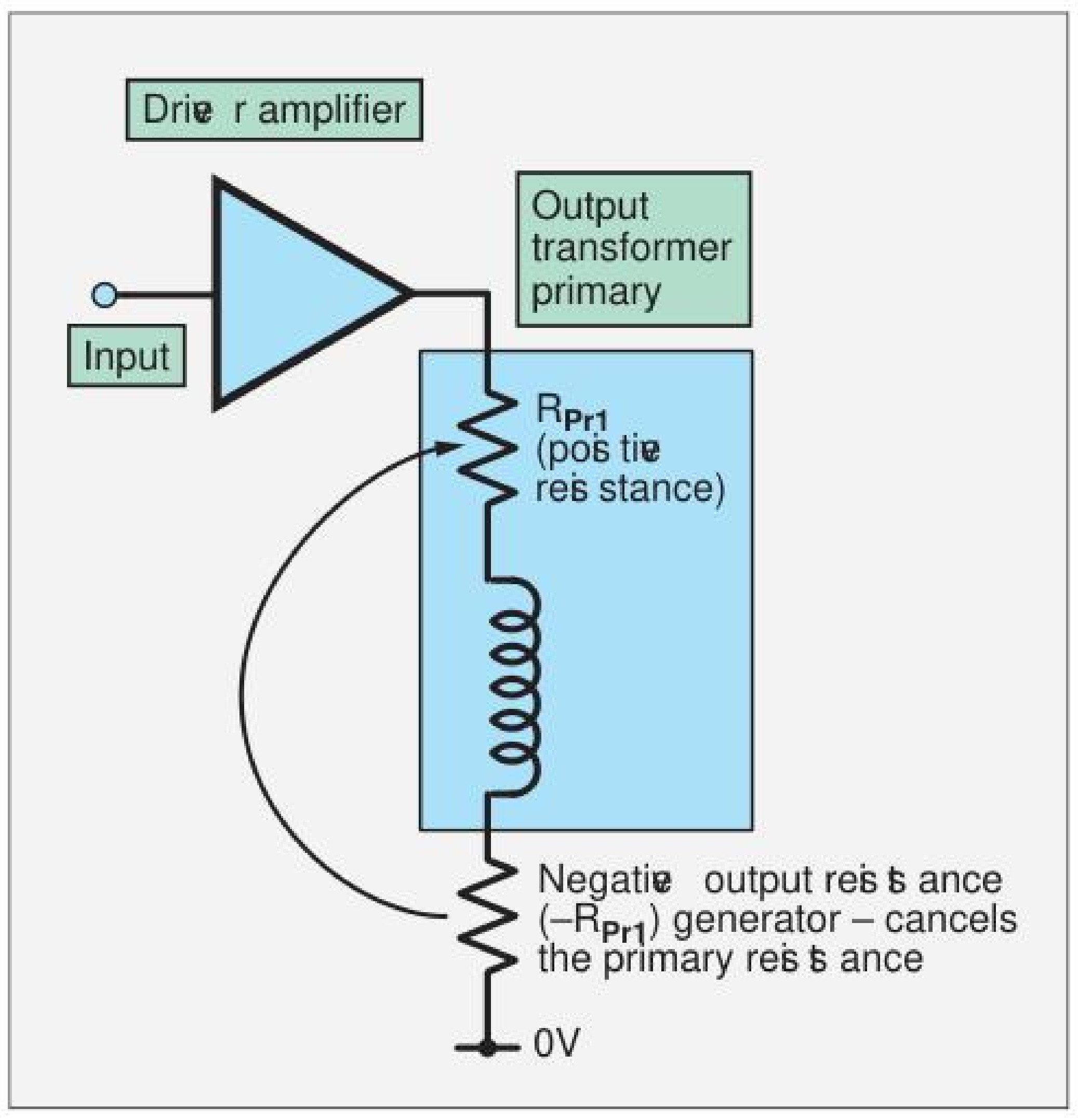

Driver amplifier
Input
Output transformer primary
R_{Pr1} (positive resistance)
Negative output resistance ($-R_{Pr1}$) generator – cancels the primary resistance
0V

Fig.40. Basic principle of reducing the transformer distortion. The negative resistance cancels out the transformer's primary DC resistance.

Transformer distortion

All transformers produce a rising distortion as the frequency gets lower, similar to acoustic instruments, magnetic tape, capacitors and loudspeakers. Transformer distortion harmonics tend to be mainly third order plus a bit of second order. Solid-state electronics such as op amps, class AB power amps and digital-to-analogue converters all have the opposite effect, higher-order distortion rising with frequency. Some audio people think these two characteristics complement each other, which is why one finds expensive gold-plated silver-wound transformers installed in expensive digital Hi-Fi systems. There is also a huge demand for class-A Neve-style transformer-coupled preamplifiers, such as the 1073.

I take the view that – within reason – low-order harmonic distortion is enhancing on simple audio signals, such as a solo voice and drums, but bad on complex mixes of signals, for example piano and choral music. This is because dissonant intermodulation products arise with multiple tones on systems with high THD. I've decided to offer a choice here, normal transformer distortion of about 1% at 20Hz (shown in Fig.37) or a special distortion-cancelling circuit built around IC2b, which lowers LF distortion to around 0.02%, as shown in Fig.38.

Distortion minimisation circuit

The BBC originally used huge expensive transformers with 80% nickel 20% iron cores for their own in-house-built equipment, as shown in Fig.39 This was very effective in minimising distortion. When sound mixers began to be bought in from private industry, enterprising engineers developed circuit tricks to get the same performance using cheaper components. Most involved negative feedback from an extra winding, such as some Neve designs. Another method was developed so that ordinary off-the-shelf transformers could be used. It was well known that transformers gave less distortion when driven from zero source impedance. This was because the current drawn by a transformer is distorted because of the hysteresis and saturation effects of the iron core. The saturation effect gets worse as the frequency decreases, since there is more magnetic energy to store for each cycle, accounting for the low-frequency rise. Despite these tricks it is worth noting that some residual distortion is still developed because of the series resistance of the primary wiring, even if driven from a zero-ohm output. Then some bright spark figured that if this resistance could be cancelled out by a negative resistance, distortion should be eliminated, as shown in Fig.40.

A circuit developed by Calrec in conjunction with Swedish transformer maker Lundahl is shown in Fig.41. The lower op amp IC2b is the negative-resistance generator. It works by developing a voltage in anti-phase to the current flow by using a sense resistor (R27). If a current goes into the upper end of the sense resistor the voltage developed across it goes down rather than up, as shown in Fig.42. It should be noted this circuit uses a degree of positive feedback and if the negative resistance exceeds the resistance of the primary, the circuit will oscillate. The amount of positive feedback is set by the lower-arm feedback resistor (R25), and this should be adjusted to suit the transformer used. The original Calrec circuit used 2kΩ with a Lundahl LL1517 transformer, which is now very expensive. I use the Vigortronix 49% Ni core VTX 101-3001 with R25 set to 3.9kΩ. Another source of distortion is ground currents. By feeding the transformer return current into the output of IC2b, it is conveniently diverted to the power rails.

To achieve the lowest distortion, always drive a transformer directly from the output of the drive amplifier using DC coupling. Adding a coupling capacitor causes the LF distortion to rise again because of the

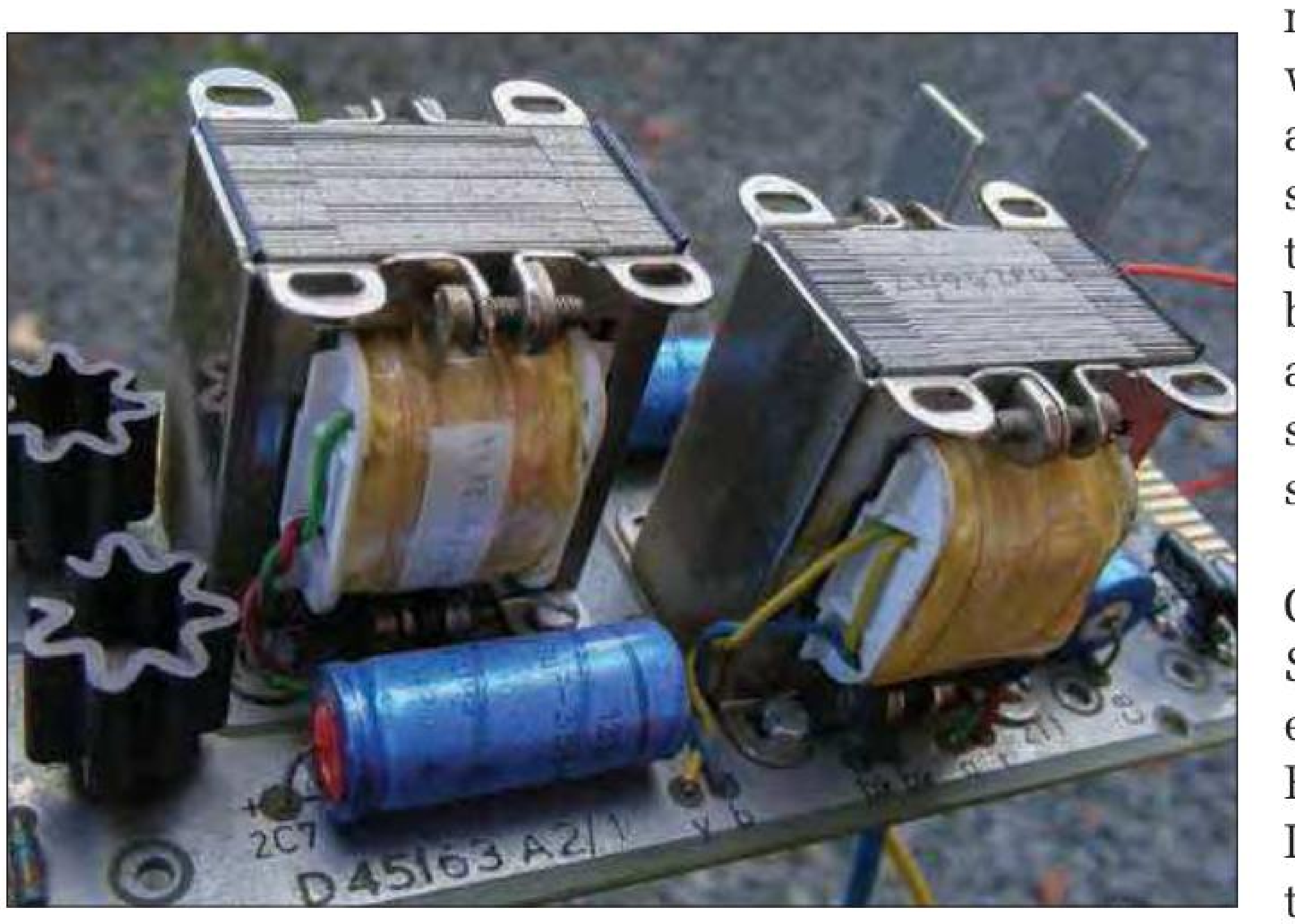


Fig.39. Heft rather than feedback – the BBC used to use conventionally driven large (43mm high) nickel-core transformers to get low distortion.

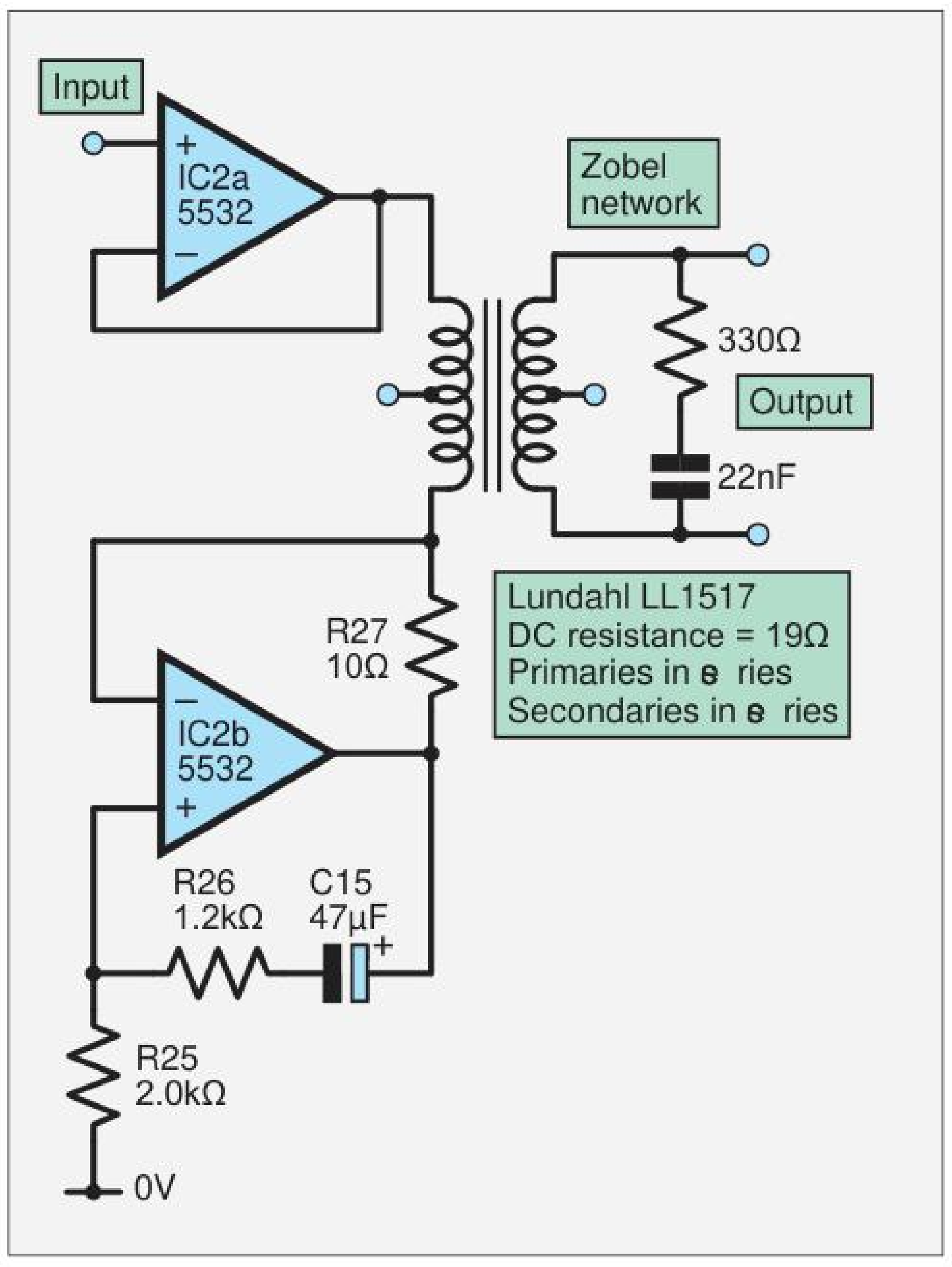


Fig.41. The distortion-reduction circuit used on late 1980s Calrec broadcast desks using a Lundahl output transformer.

capacitor's reactance, as shown in Fig.43. One problem with driving transformers directly is the low DC resistance of the winding, which can give rise to high fault currents if an offset voltage develops. The 5532 seems to be able to survive such situations, but its dissipation rating maybe exceeded in the worst-case situation where both op amp outputs are latched to opposite power rails. It's a worthwhile safety precaution to add clamping diodes (shown dotted in Fig.42) from the outputs to the rails to deal with possible voltage spikes caused by the transformer driving faulty leads.

Capacitor distortion

In Rupert Neve's obituary (*JAES*, March 2021), Malcolm Atkin, MD of Audio Consultants Ltd, recalled Neve describing what caused the unique sound quality of his mixing console installed at Sir George Martin's Air recording studios in Montserrat. He said it was not just down to the transformers, but tantalum capacitors. Using tantalum capacitors for signal coupling (especially when unbiased and driving low impedances) gives a similar low-frequency distortion rise to transformers. Fig.44 shows this capacitor distortion on the microphone-preamplifier. Ordinary wet aluminium electrolytics also make this distortion, but around five times less.

Going bipolar

Bipolar wet aluminium electrolytics are almost distortion free and provide full protection from hard offsets of either polarity. This approach was used by Clive Green in his Cadac mixers used in most West End theatres. Connecting two polarised capacitors back-to-back effectively makes a bipolar capacitor, but some distortion is still present. To eliminate this, a few volts of bias at the junction is needed.

Inactivity can kill

One problem little known about these wet bipolar capacitors is their short shelf life.

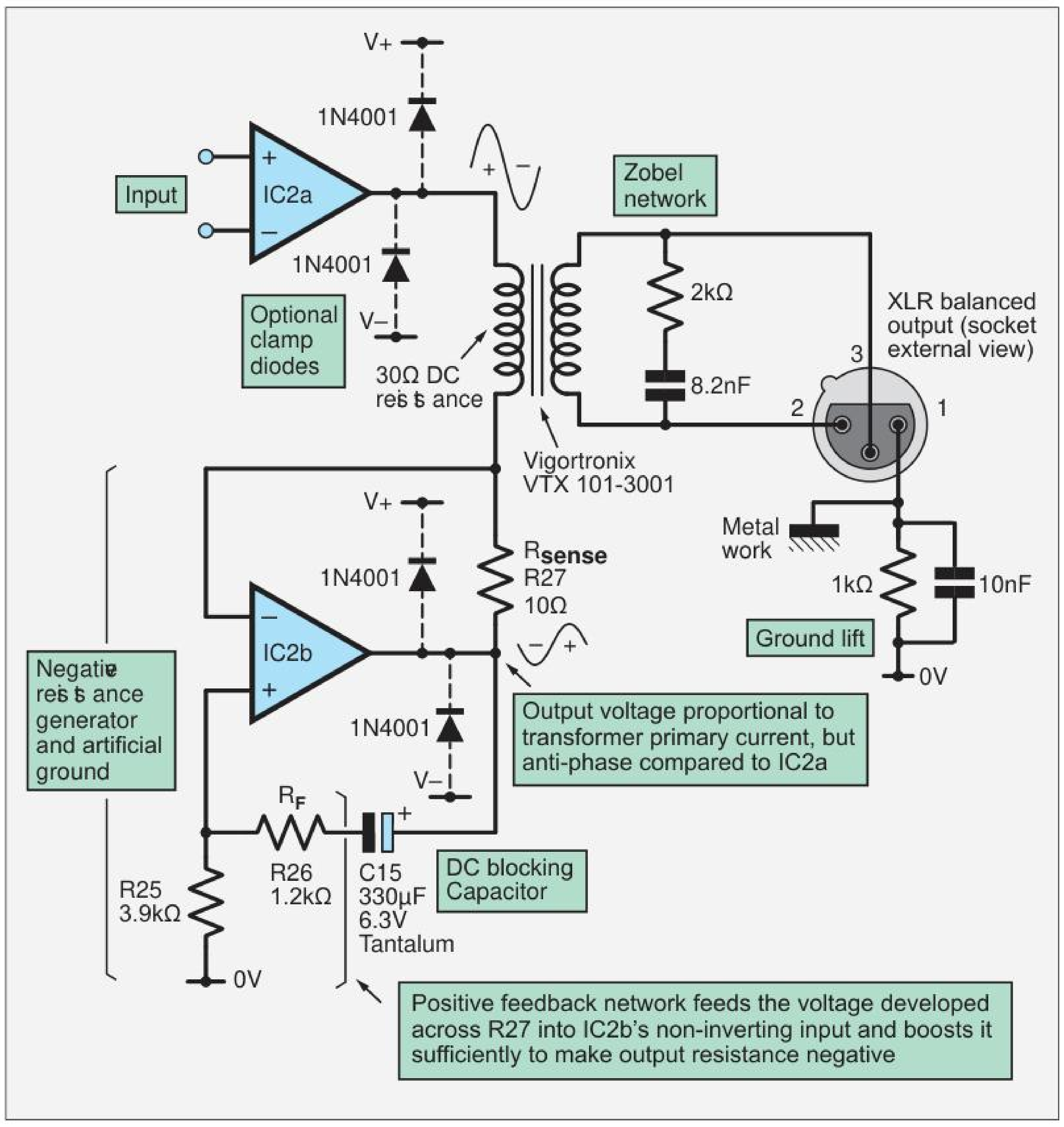

V+
1N4001
Input
IC2a
+
–
Zobel network
1N4001
2kΩ
Optional clamp diodes
V–
30Ω DC resistance
8.2nF
XLR balanced output (socket external view)
3
2
1
Vigortronix VTX 101-3001
V+
Metal work
Rsense
R27
10Ω
1N4001
1kΩ
10nF
IC2b
Ground lift
0V
Negative resistance generator and artificial ground
1N4001
Output voltage proportional to transformer primary current, but anti-phase compared to IC2a
V–
RF
R25
3.9kΩ
R26
1.2kΩ
C15
330µF
6.3V
Tantalum
DC blocking Capacitor
0V
Positive feedback network feeds the voltage developed across R27 into IC2b's non-inverting input and boosts it sufficiently to make output resistance negative

Fig.42. The negative resistance is developed by producing an anti-phase voltage drop from the current passing though sense resistor R27. The effect is boosted by positive feedback network R26 and R25. DC has to be blocked by C15 to prevent the op amp going off-set.

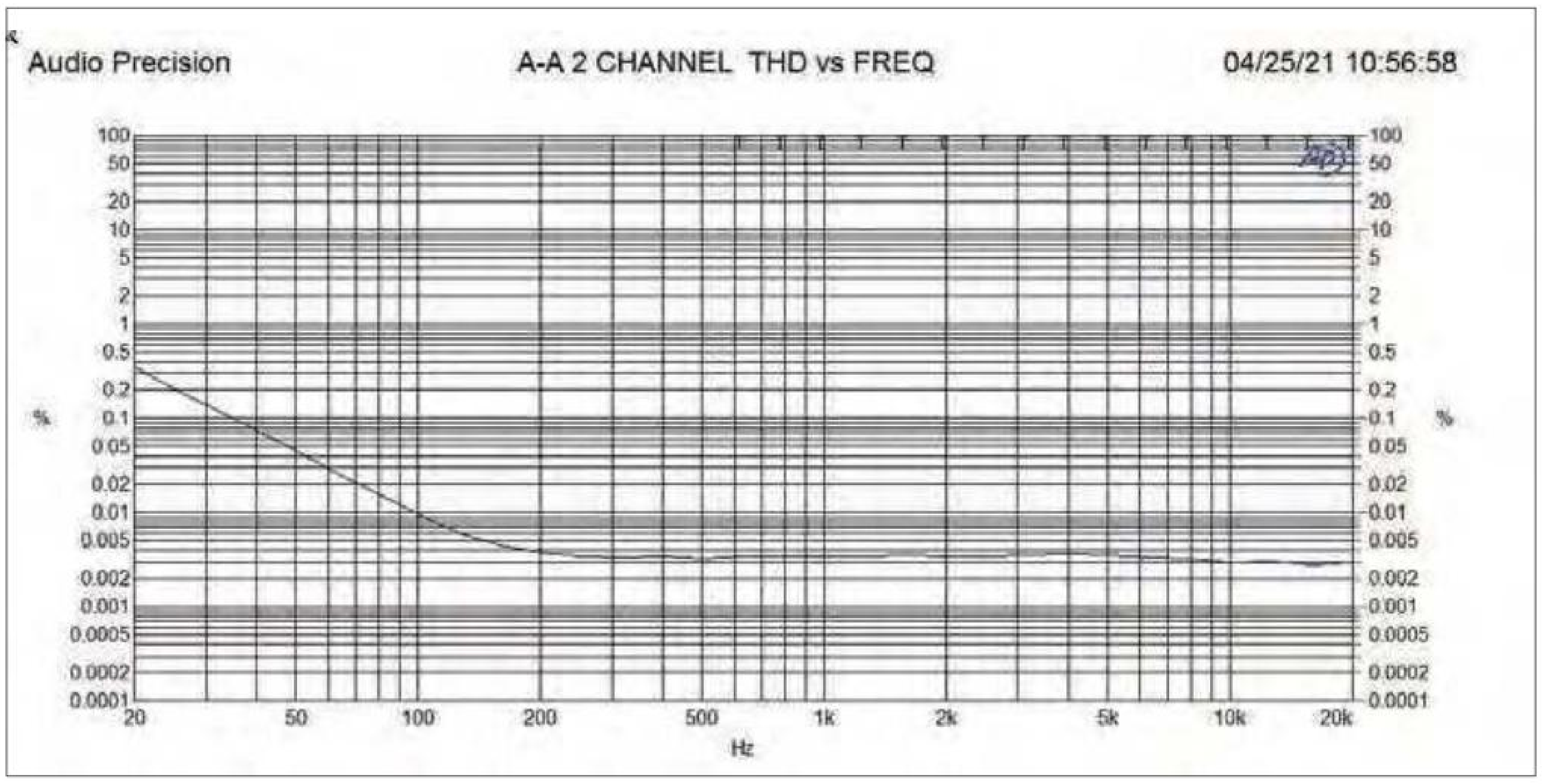


Fig.43. The output transformer has to be directly driven / DC coupled. Adding a 47µF bi-polar capacitor in series with the output of IC2a spoilt the distortion cancelling effect. I found enclosing this capacitor in a negative-feedback loop around IC2a eliminated the distortion, but then caused low-frequency ringing around a few hertz. Negative resistance is a good way of making an oscillator. This is a work in progress.

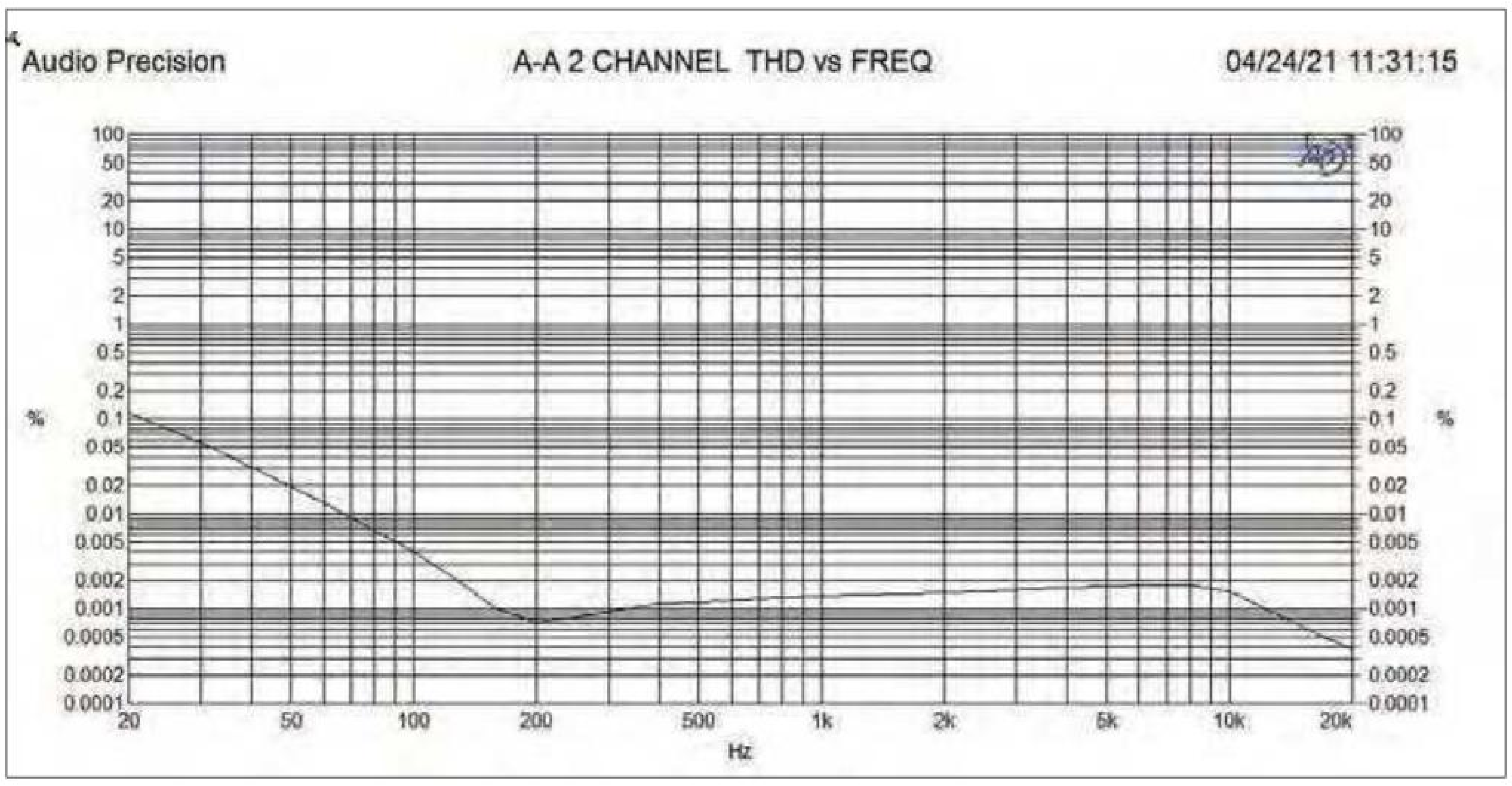


Fig.44. Distortion effect of a single 100µF 20V tantalum capacitor driving 13.6Vpk-pk into 600Ω unbalanced output (ie, no transformer). It is reverse polarised each cycle, the voltage increasing as the frequency decreases, causing a rise in distortion at low frequencies. It is unlikely the capacitor will normally be driven at this level.

11-3079
Rapid
200
470uF 35V Non Polarised Capacitor
280013 24/09/10
18
1547091
ALUMINIUM ELECTROLYTIC CAPACITOR
CD71 35V470uF 13X21
200PCS
Checked MAY 2021 50% RR

Fig.45. Bipolar electrolytic capacitors have negligible distortion, but they can degrade if not used. All of these Suntan capacitors almost exploded in storage.

Tel. 01582 47000
Fax. 01582
www.jprelec.co.uk
JPR
Order Code: 100-668
Batch: 38509
Qty: 10

Fig.46. The Hitano capacitor brand was no better than Suntan in terms of component degradation.

I've just dumped a load of Suntan capacitors from Rapid and some Hitano types from JPR which exploded in storage after a few years. When I complained, they pointed out the data sheet specified they need a polarity reversal every 250 hours. Those from Nichicon and Panasonic have the same requirements. They have to be used or they die – see the photos in Fig.45. and Fig. 46. A sensible check is to measure the capacitance. If it has markedly risen from its stated value then it's a sign that the rot has already started, and the dielectric film is thinning. One manufacturer whose products do not suffer from this defect is the yellow Nitai type shown in Fig.47.

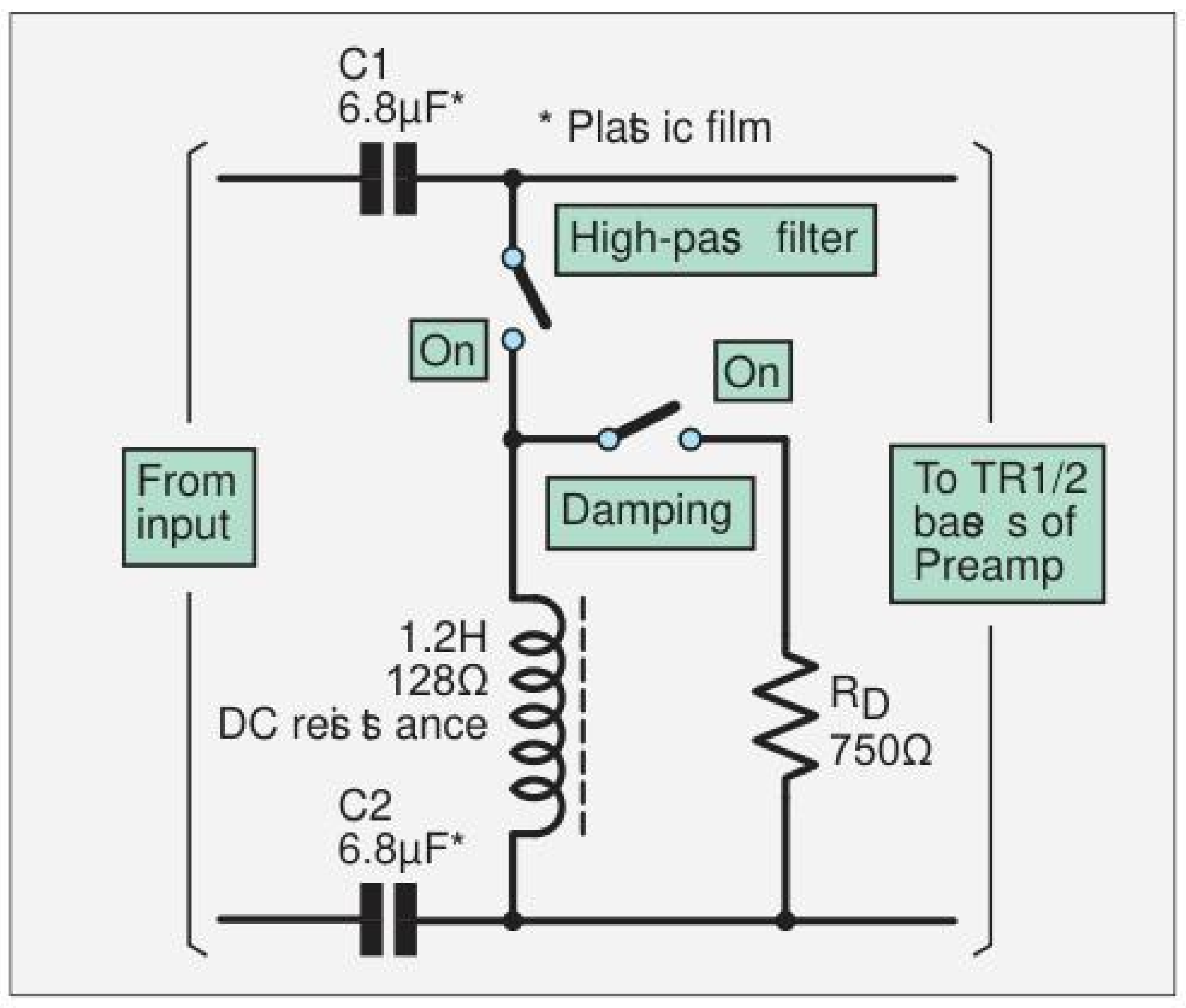

C1
6.8µF*
* Plastic film
High-pass filter
On
On
From input
Damping
To TR1/2 bases of Preamp
1.2H
128Ω
DC resistance
RD
750Ω
C2
6.8µF*

Fig.50. A high-pass filter can be placed directly on the input to the preamplifier. For better headroom, remove low-frequency signal rubbish *before* amplification.

The Midas touch

The clever way round this problem is a technique developed by Midas who made the mixers and sound systems used by Pink Floyd. Aged 13, I remember being taken to their factory near Euston in 1975 by my uncle who worked there as a test engineer. I saw the best audio design, construction and components. They had Bourns conductive plastic pots and Philips TDA1034 op amps, (later renamed the NE5534) before anyone else. A quirk of the 5534 is that sinking a small current into the output of the 5534 reduces its distortion. The engineers at Midas (who I suspect discovered this technique) also combined it with a bipolar capacitor biasing circuit, as shown in Fig.48. This worked wonders with tantalum capacitors. The resulting curve is shown in Fig.49. We now have a virtually distortionless coupling capacitor that lasts a lifetime. One of the Midas desks is now in the UK's National Science and Media Museum's mixer collection.

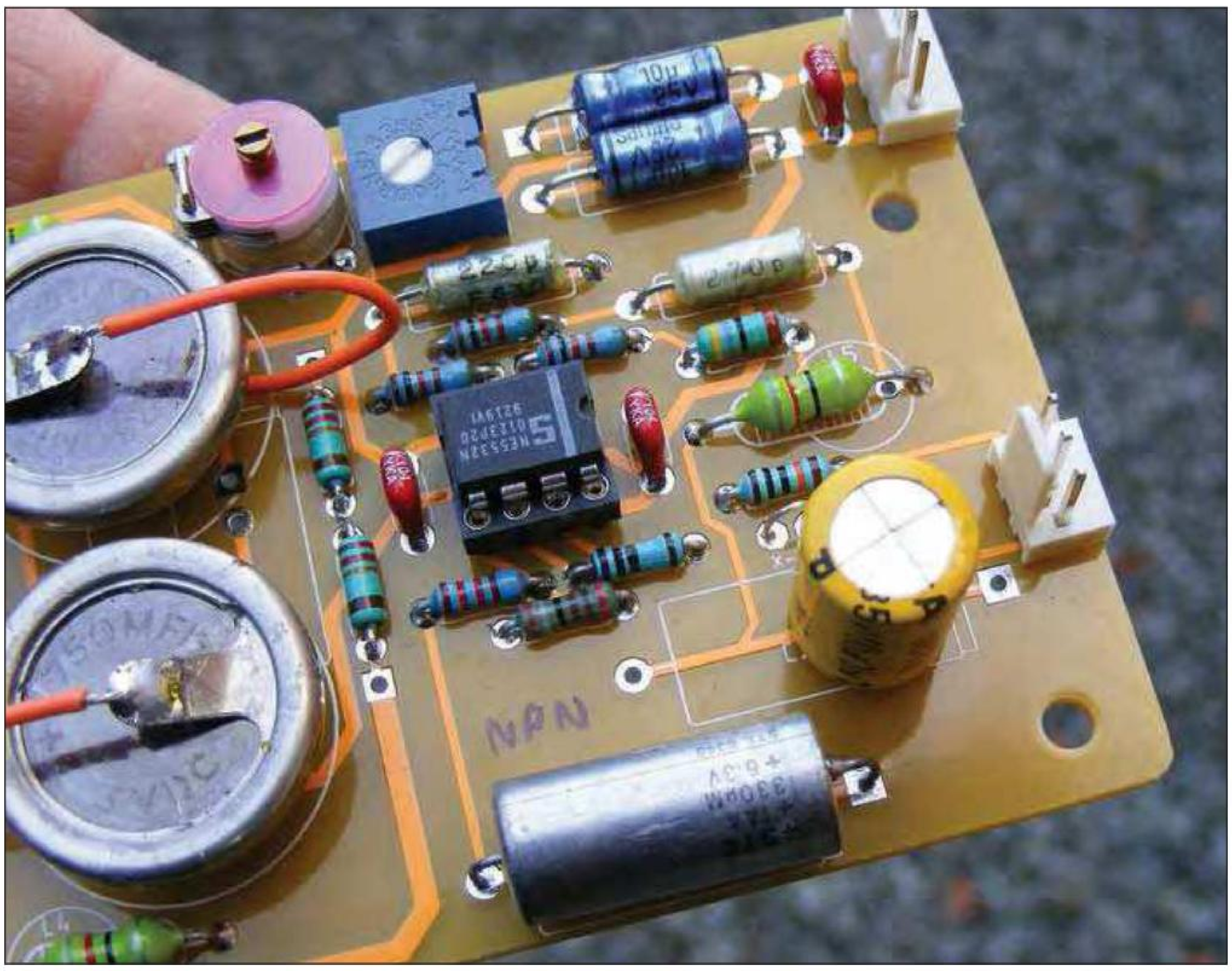


Fig.47. These yellow Nitai capacitors gave no storage degradation problems, but I'm not sure if you can still get them.

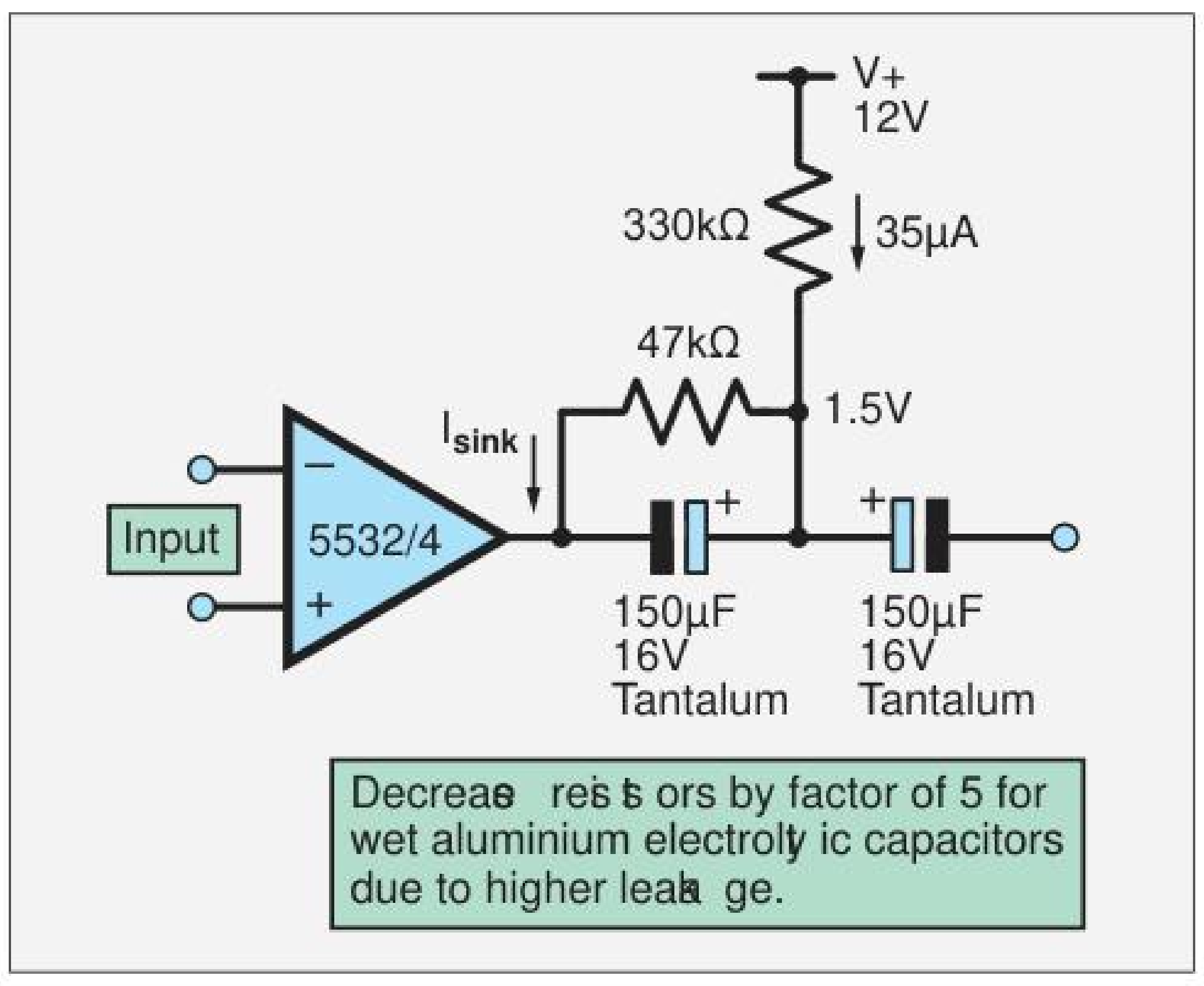

V+
12V
330kΩ
35µA
47kΩ
1.5V
Isink
Input
5532/4
–
+
+
+
150µF
16V
Tantalum
150µF
16V
Tantalum
Decrease resistors by factor of 5 for wet aluminium electrolytic capacitors due to higher leakage.

Fig.48. The biased bi-polar tantalum capacitor circuit used in Midas mixers. Low distortion, lasts for ever. Midas also biased the 5534 output stage into displaced class A for lower distortion. (Although in this case the current sunk will have little effect – around 5mA is needed).

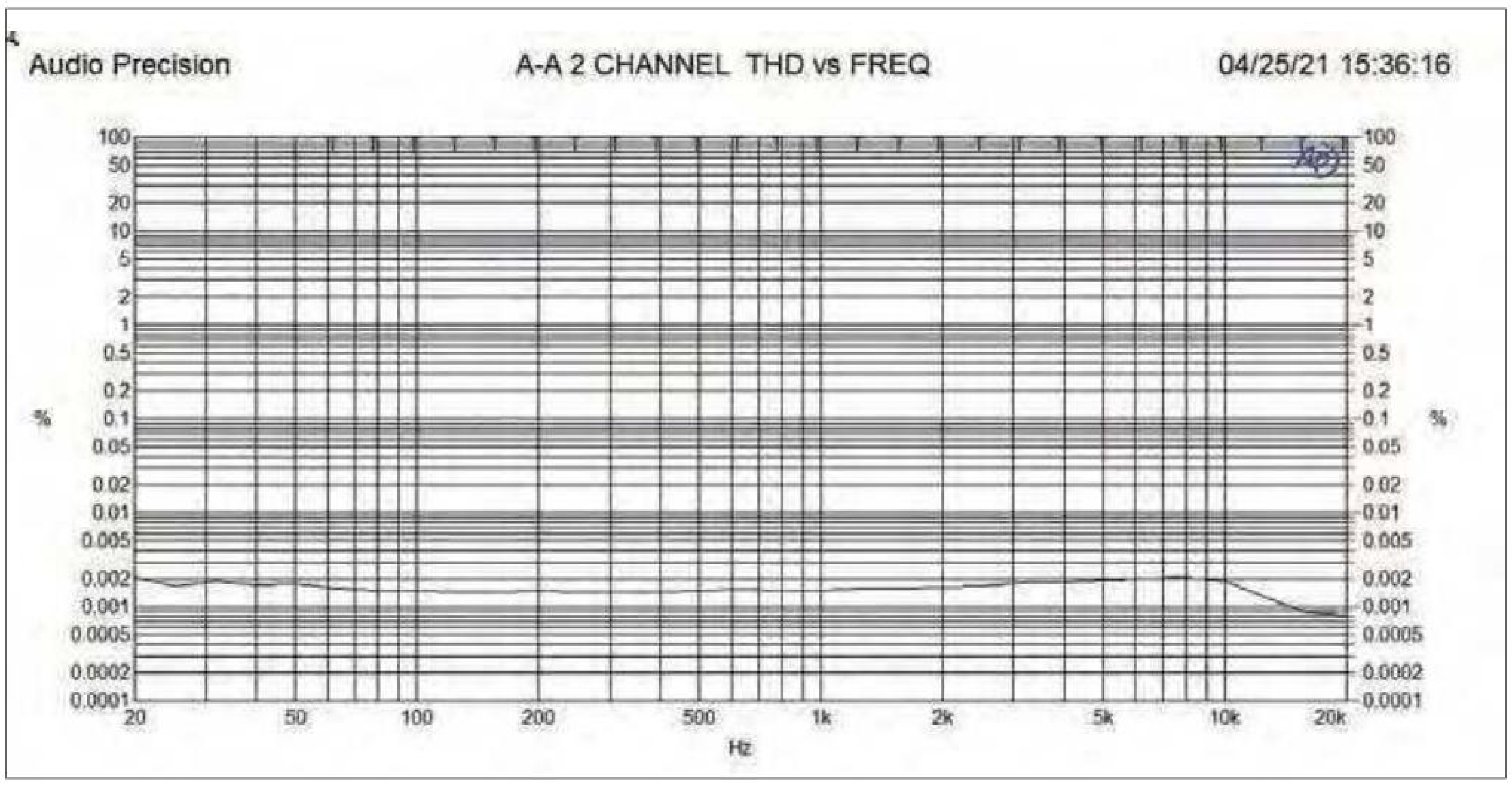


Fig.49. The effect of the Midas circuit on a $7V_{pk-pk}$ signal into 600Ω (no transformer).

Low-cut filter

Wind noise, vocal pops and handling cause microphones to generate a lot of low-frequency transients which cause all sorts of problems, such as clipping, intermodulation and transformer saturation. These are best removed as soon as possible in the signal chain. A simple compromise is to put a smaller capacitor in series with C8, C9 and VR1 (the gain control). This can consist of two 22µF tantalum bead capacitors in parallel back-to-back. These are then shorted out by a switch to turn the filter off. Unfortunately, the cut-off frequency varies with gain setting. A selection of capacitors could be wired to an extra gang in a gain

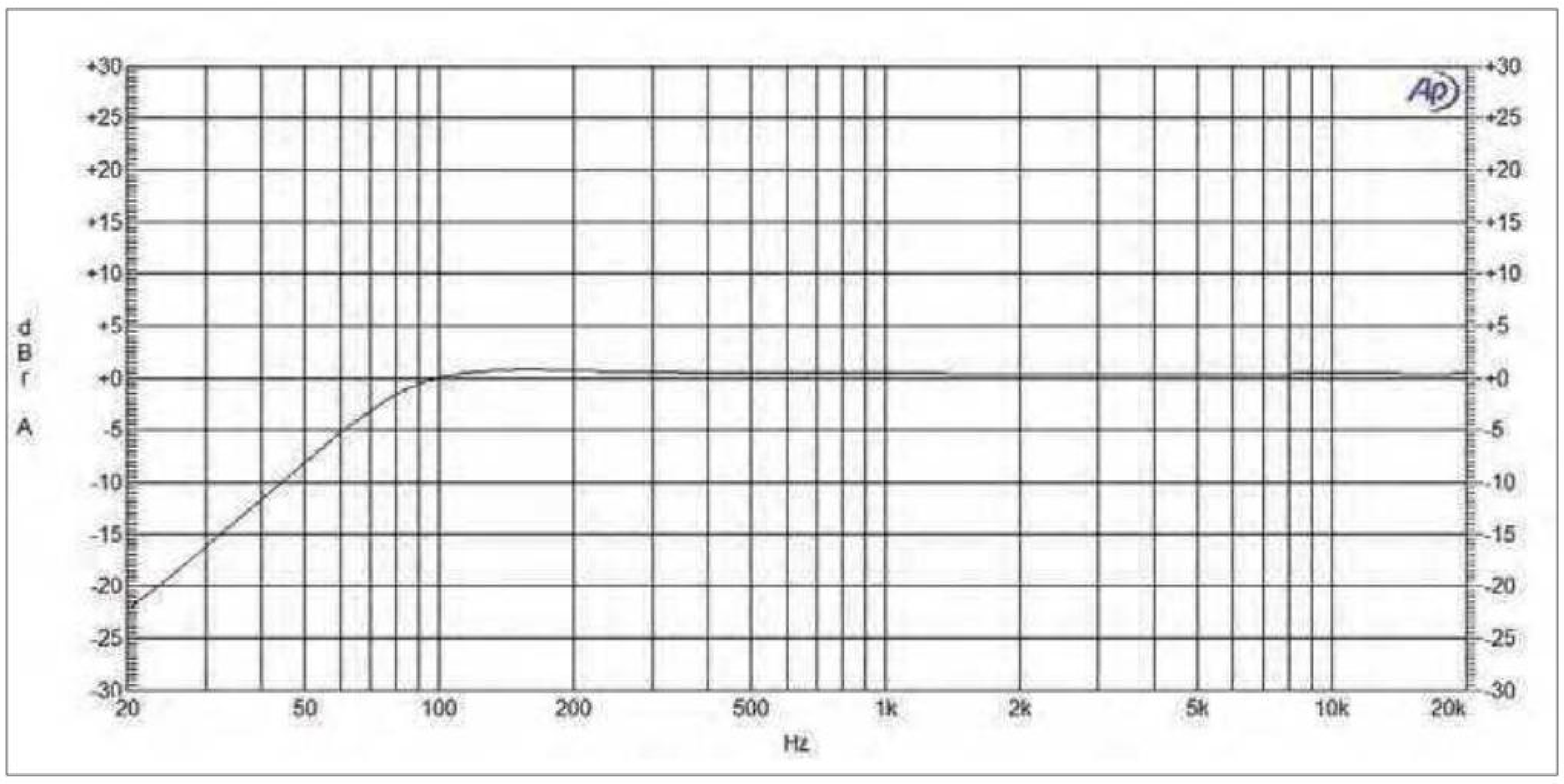


Fig.51. The second-order high-pass filter response from Fig.50 with a cut-off frequency of 95Hz, which should be changed to suit different voices.

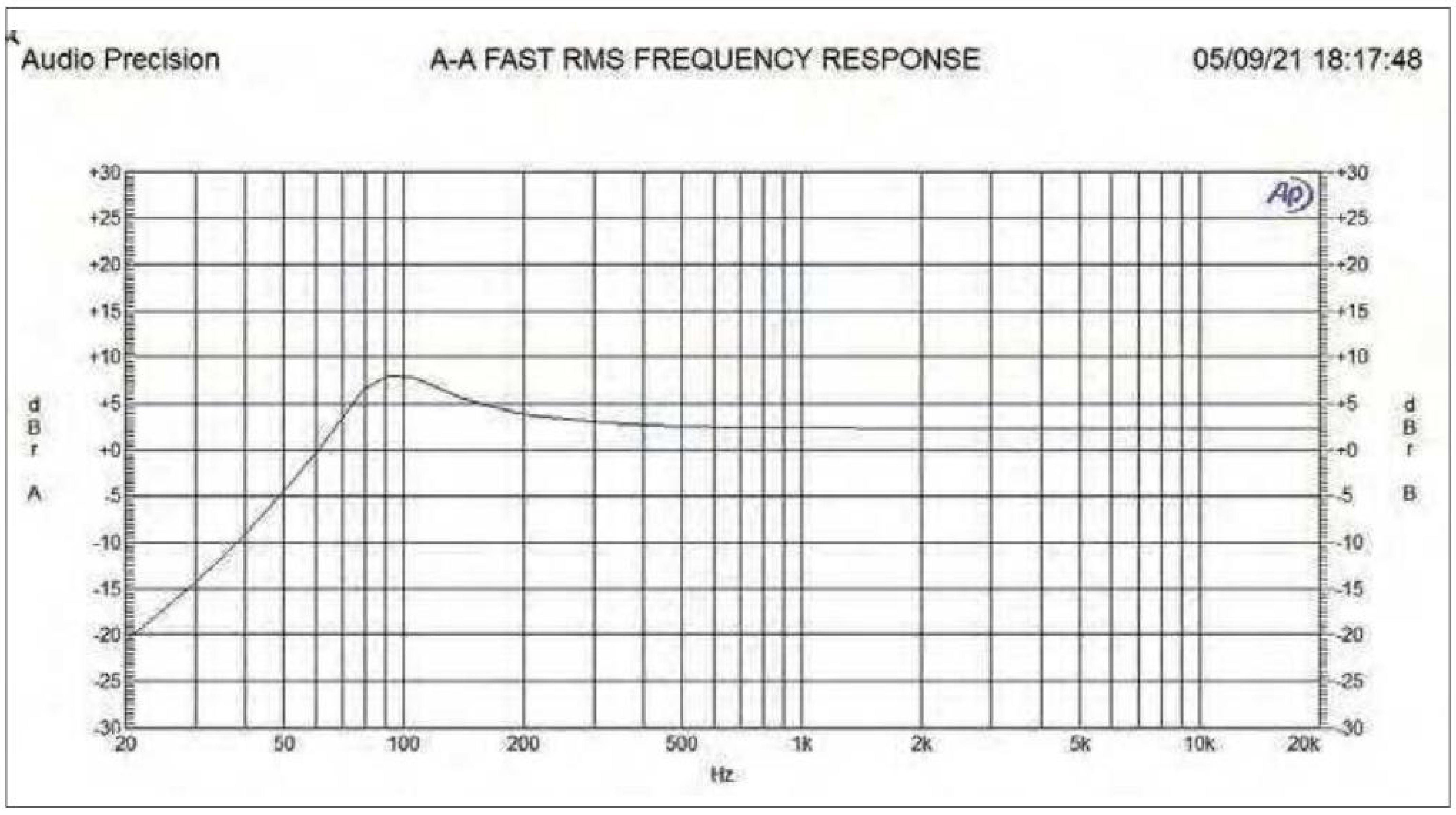


Fig.52. Effect of removing the damping resistor R_D in Fig.50. The humped characteristic is enhancing in some speech applications.

switch. A better solution is a 1200mH inductor strapped across the input after the coupling capacitors C1 and C2, as shown in Fig.50. This does not cause a significant distortion- or impedance-induced noise problem. Reducing the capacitors to 6.8µF steepens the slope and raises the cut off frequency to that shown in Fig.51. The inductor must be well shielded to avoid hum pick-up, such as a ferrite pot core. Leaving the 750Ω damping resistor off gives a resonant hump which can be useful for adding 'warmth' to voices, as shown in Fig.52. This can be made switchable.

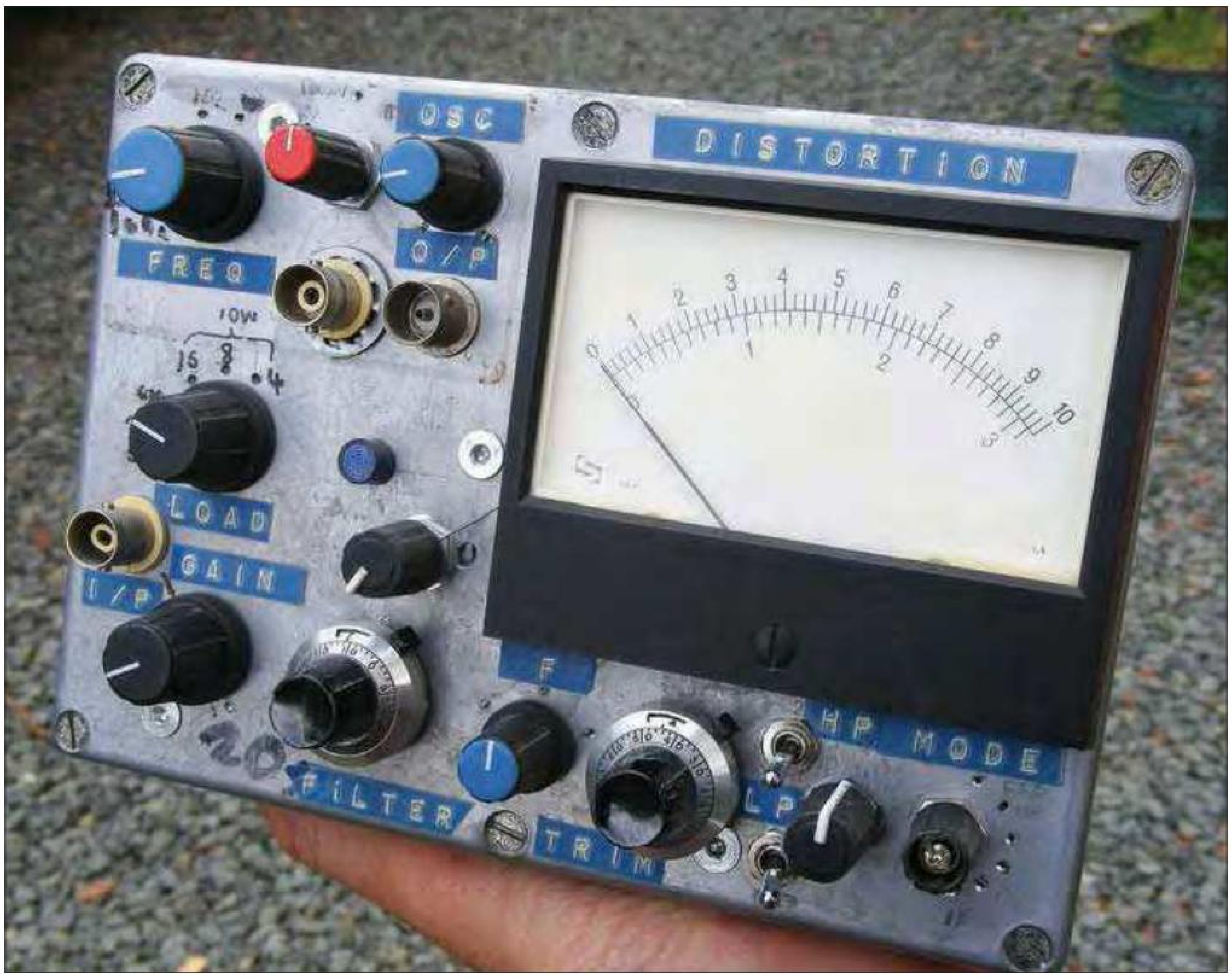


Fig.53. This Linsley-Hood distortion analyser gave 25 years of solid service.

Measuring distortion

Distortion is a measurement requiring expensive equipment. I started off with a homemade *ETI* Linsley-Hood distortion analyser (see Fig.53), and then moved to a Lindos, one of the best examples of degenerate digital design with a grey-on-grey LCD. I recently moved to the Audio Precision instrument shown in Fig.54 – having waited 15 years for the price to drop like a good car from £14,000 to £1500. The software is horrid, like Windows Vista, but the hardware (apart from the noisy fan) is unsurpassed.

PNP transistors

There is provision on the PCB to allow PNP transistors to be used to take advantage of their slightly better noise and R_{bb} figures compared to their NPN complements. The polarity of supplies to the collector (R7 and R8) and emitter resistors (R9 and R10) can be reversed by means of links. Notice that D5 and D6, C8 and C9 also have to be reversed. Fig.55 shows how centre-collector Japanese transistors, such as the 2SD655 are installed.

48V transistor power

Groner found running the transistor collectors off the 48V phantom power rail reduced the noise at minimum gain by 5.3dB. This mod can only be done with NPN transistors. The resistors R7 and R8 have to be increased to 9.1kΩ 0.5W. This can be done by simply putting in 6.2kΩ resistors into the positions marked REX1 and REX2 on the PCB, and putting a diode in the link to the positive 15V rail. PNP transistors may benefit by taking the emitter resistors to +48V which will provide a more constant current, giving better matching. (There is no provision on the board for this – this is for experimentation only, so implementing it will be a bit messy!)

Battery version

The second op amp stage can be eliminated by feeding the outputs of the gain stages (IC2) into an output transformer or balanced output directly. This will reduce current consumption by 4mA and avoid the differential amplifier noise. I've found the Vigortronix VTX-101-007 to be an excellent transformer for this job. It is possible to then use the preamplifier with a couple, or even four PP3 batteries as a remote gain booster. Current consumption

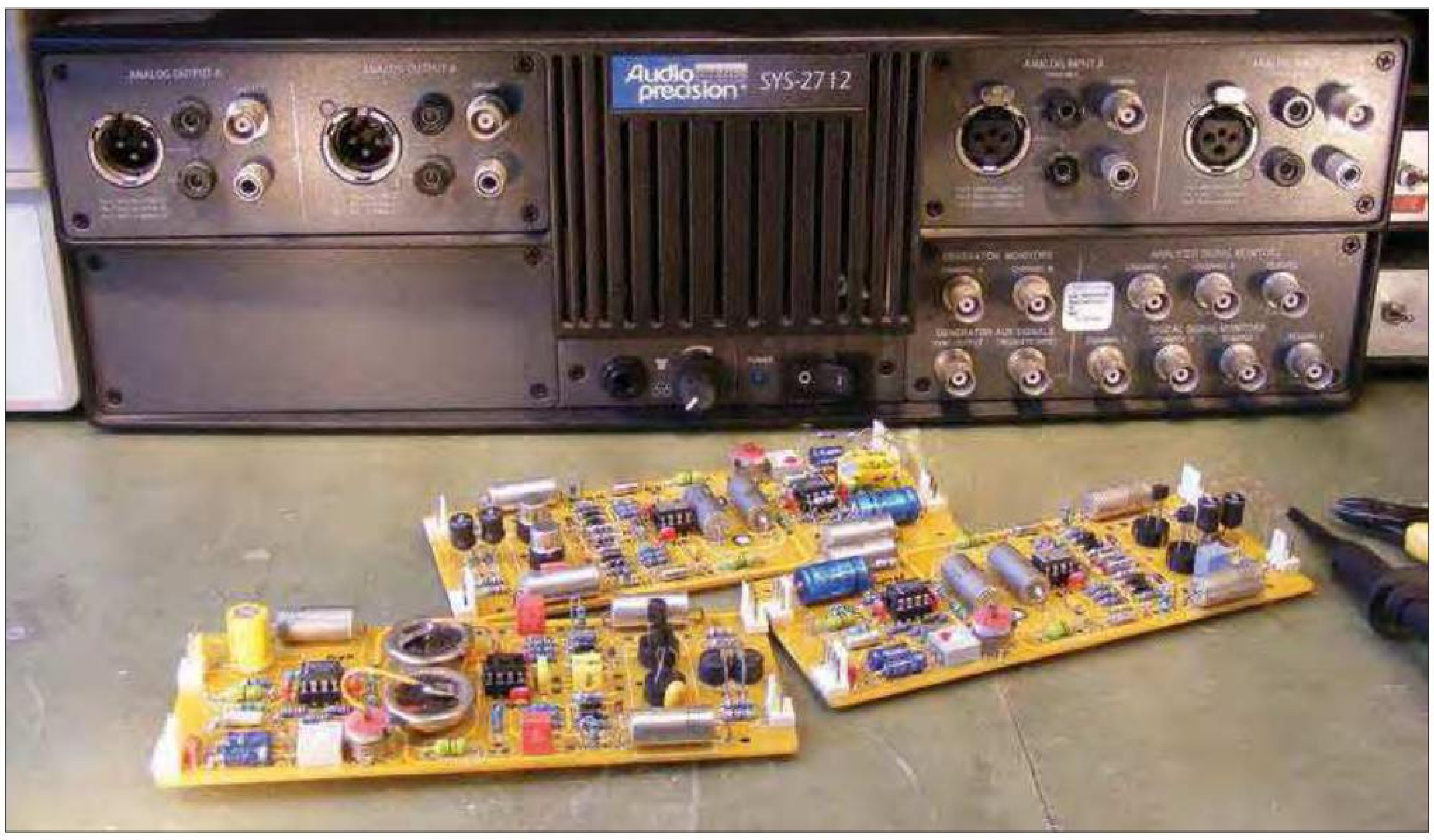


Fig.54. My Linsley-Hood unit has now been replaced with this Audio Precision unit, so graphs can be more easily produced.

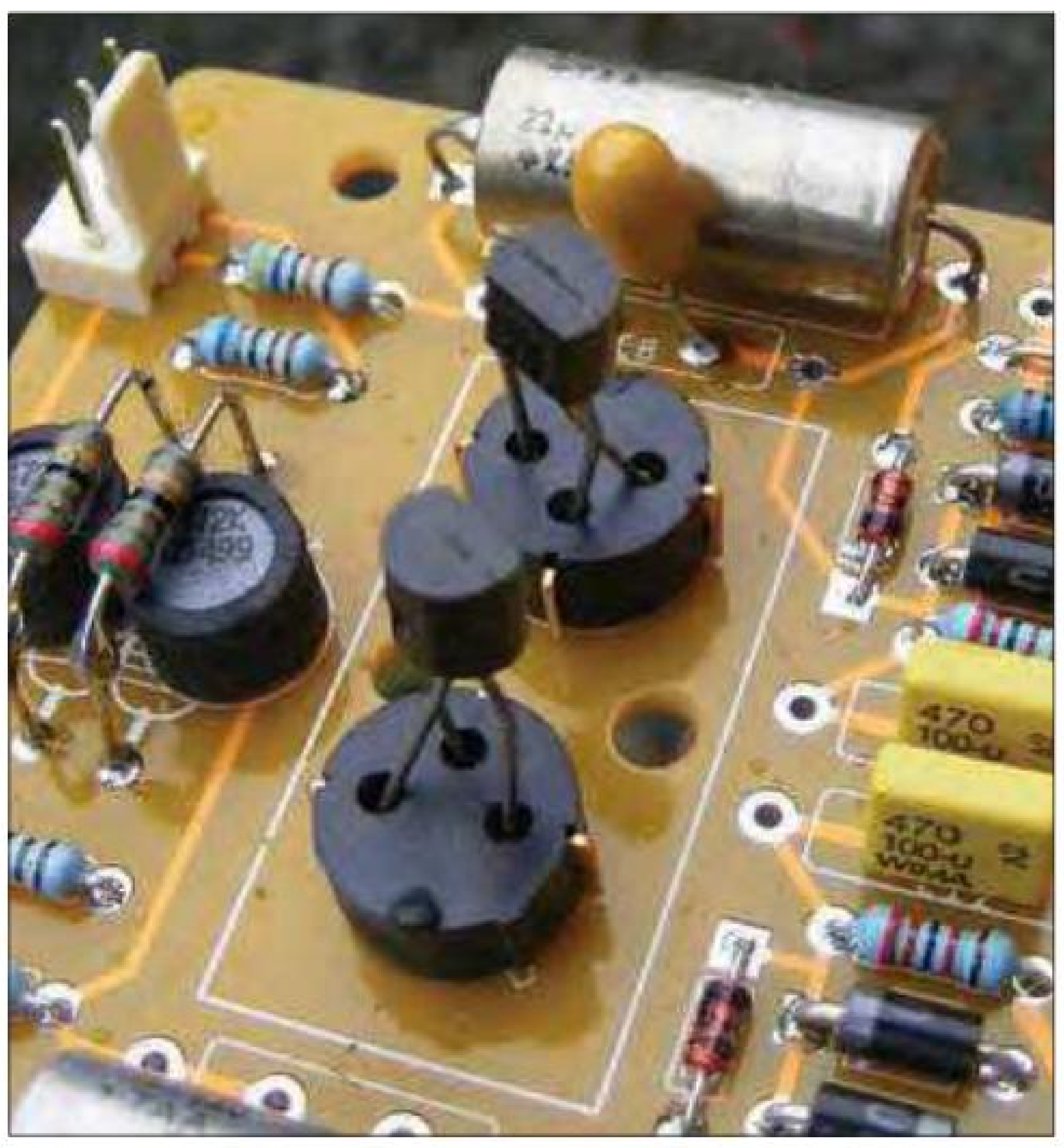


Fig.55. Most low-noise Japanese transistors have their collectors in the centre. These have to be inserted in TO5 sockets, as shown here.

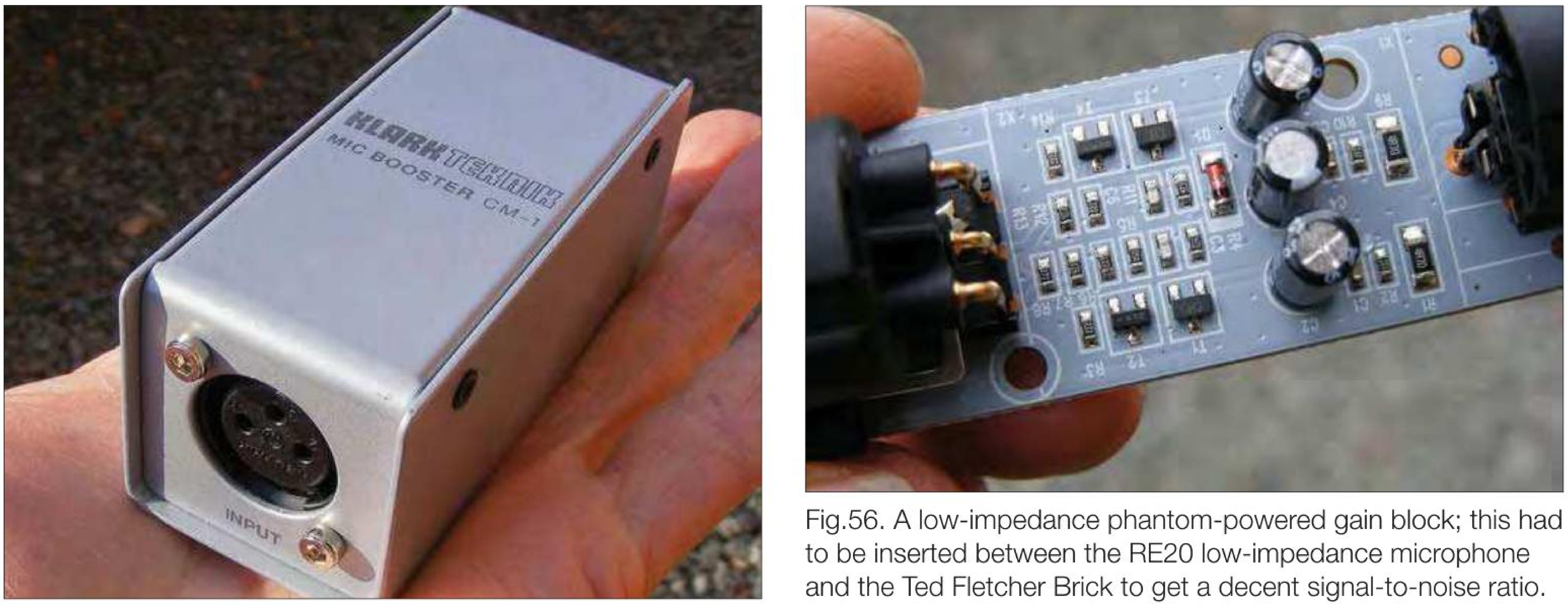


Fig.56. A low-impedance phantom-powered gain block; this had to be inserted between the RE20 low-impedance microphone and the Ted Fletcher Brick to get a decent signal-to-noise ratio.

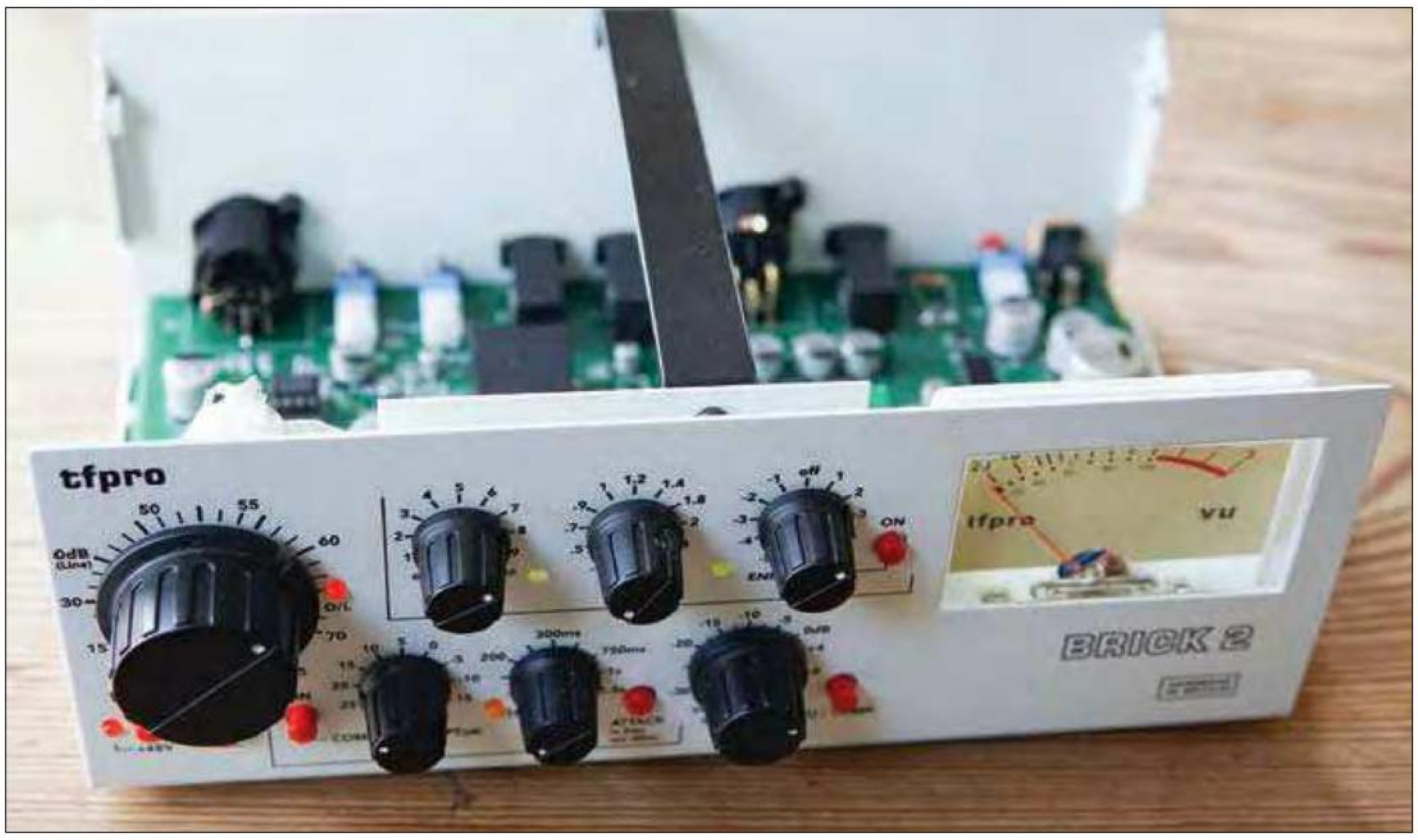


Fig.57. The Ted Fletcher Brick is an amazing microphone preamplifier plus processor for studio condenser microphones, but not suitable for low impedances, hence the replacement design given here.

on ±9V was 13.8mA. Amazingly, I found the unit works down to ±4.5V. Distortion will of course be much higher for the battery version. Large rail decoupling capacitors of say 470µF will reduce it. I'm thinking of making a phantom-powered single-rail version, like the gain booster shown in Fig.56.

Final thoughts

What started out as a simple microphone-preamplifier has now morphed into a complex piece of studio-quality equipment taking a month of work. It won't fit into the vocoder box now, so it will have to stand alone. So far it has compared favourably with the £700 Ted Fletcher Designs Brick microphone-preamplifier shown in Fig.57.

Leading on

There's no point using a low-noise amp with a noisy lead, so next month in *Practically Speaking* I'll be showing how to make a top-quality microphone lead.

1966 Practical Electronics Transistor Guide – now complete!

You may remember a few issues back we included part of a handy *Transistor Guide* from the May 1966 issue of *Practical Electronics*. It was incomplete because our well-thumbed copy had lost a few pages. Well, a couple of readers were kind enough to help us out, and this month's download from the August 2021 page of the *PE* website includes the full *Guide*. Thank you David Allan and Bob Ashby.

AO*Shop*

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

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5534H metal-cased op amp	**£3.00**
LM384, TDA2030A	**£1.50**
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CA3080 VCA/VCF (vocoder)	**£2.80**
CA3082 VCA/VCF	**£4.00**
LM13600/ LM13700 VCA/VCF	**£2.00**
CA3086 transistor array	**£1.00**
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Make it with Micromite

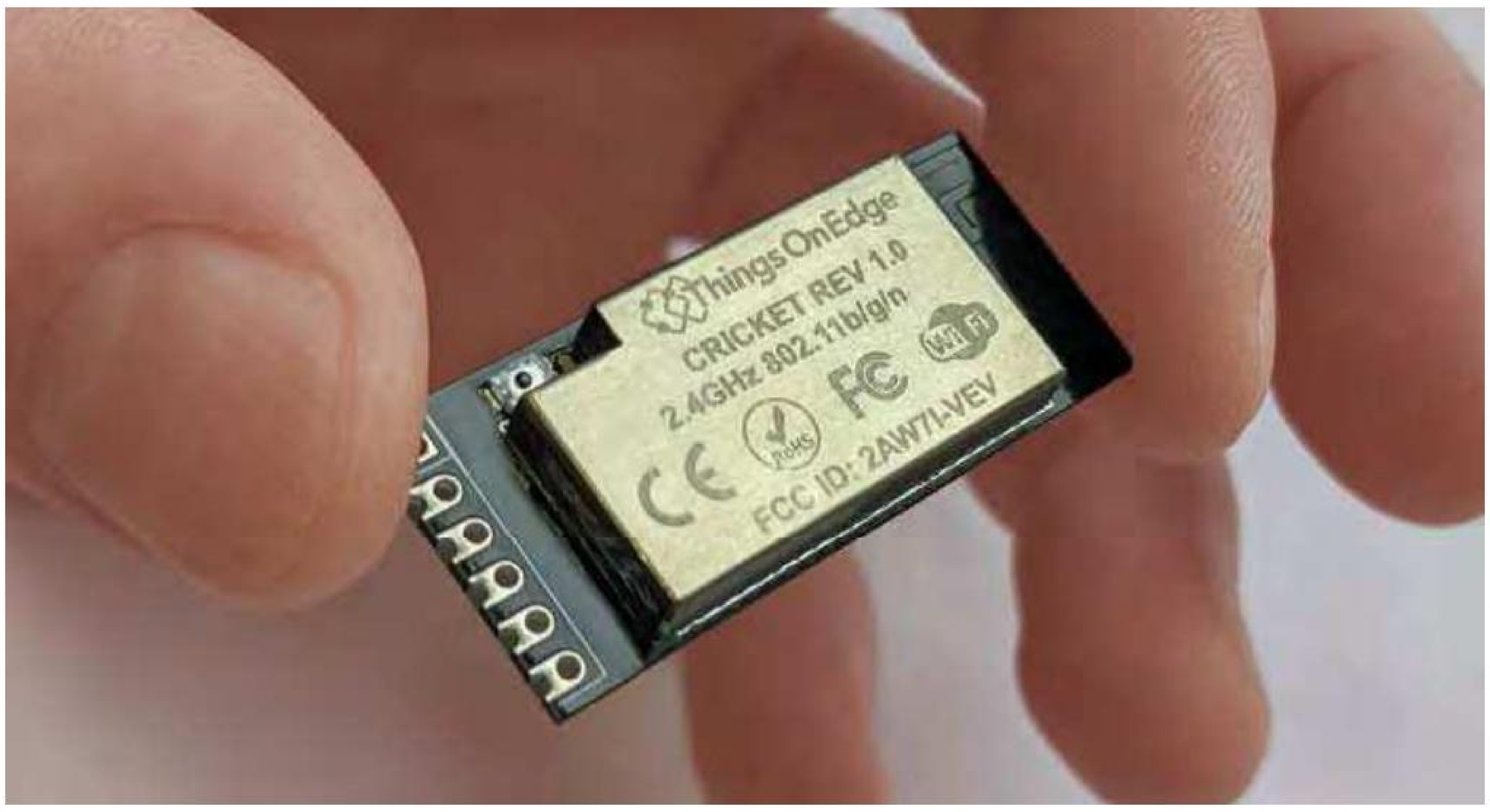
Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 31: Using the Cricket IoT module with a Micromite

In the June 2021 edition of PE there was an interesting article about the Internet of Things (IoT); more specifically, an introduction to the low-cost, yet versatile Cricket IoT module (we'll refer to it as just the 'Cricket' hereafter). The article explained that the Cricket makes it easy to get started with IoT, enabling the complete beginner to explore many possibilities of this exciting technology. I immediately ordered one so that I could start tinkering, and more importantly, to see if it lived up to the claims.

I was not disappointed. Within minutes of it dropping through my letterbox, I had the temperature in my garden being logged to the Internet. Having successfully worked through the whole of Md. Khairul Alam's *PE* article, it was very clear that the main benefits of the Cricket are its ultra-low power consumption and ease of configuration so that it can send data to a third-party web service such as ThingSpeak, or the very popular IFTTT (If This Then That). These two benefits really do make the Cricket an ideal solution for creating a battery-powered IoT sensor that 'wakes-up' at regular intervals thanks to the onboard real-time clock (RTC), read the status of up to three input pins (and/or measure the local temperature, as well as the current battery voltage), and then transmit this data to an Internet-based service via your local Wi-Fi network. Or to put it simply, by using a Cricket, it is extremely easy to make a battery powered sensor that transmits data to 'the Internet'.

I began thinking about other potential applications for the Cricket, for example, to connect up a magnetic door sensor (ie, reed switch) to one of its digital input pins so that it could then send an alert to my smartphone whenever the door was opened. This concept was quickly achieved by using a specific pin labelled 'Wake_Up'; however, there were a few minor limitations that I ran into (and in all fairness, these were probably due to my limited experience with the Cricket after just a couple of hours of tinkering!). At this stage, it was only natural for me to ponder the idea of hooking up a Micromite to the Cricket, and see what else could be achieved. Hence, the topic this month is to explore that idea further. I hope it will spark some imaginative ideas as to how you could use a Cricket in your own Micromite projects.



The compact, low-power Cricket IoT module – how easy is it to use with a Micromite?

Building Blocks

The thought process I had was really simple: use a Micromite to do the logical processing of any input device(s), and whenever required, trigger the Cricket to send the relevant data to its pre-configured web service.

My initial aim was to use a tactile button, connect it to a Micromite, and write a short MMBASIC program so that whenever the button is pressed, the code would trigger the Cricket to send me an email notification. The only decision I had to make to achieve this was choosing a web service to pre-configure the Cricket, enabling it to send emails. Due to its popularity and array of capabilities, I chose the IFTTT service: **https://ifttt.com**

You are probably thinking that there is nothing amazing about using a button, let alone wondering why I'm bothering to even use a Micromite for such a simple scenario (after all, you could just connect the button directly to the Cricket). The

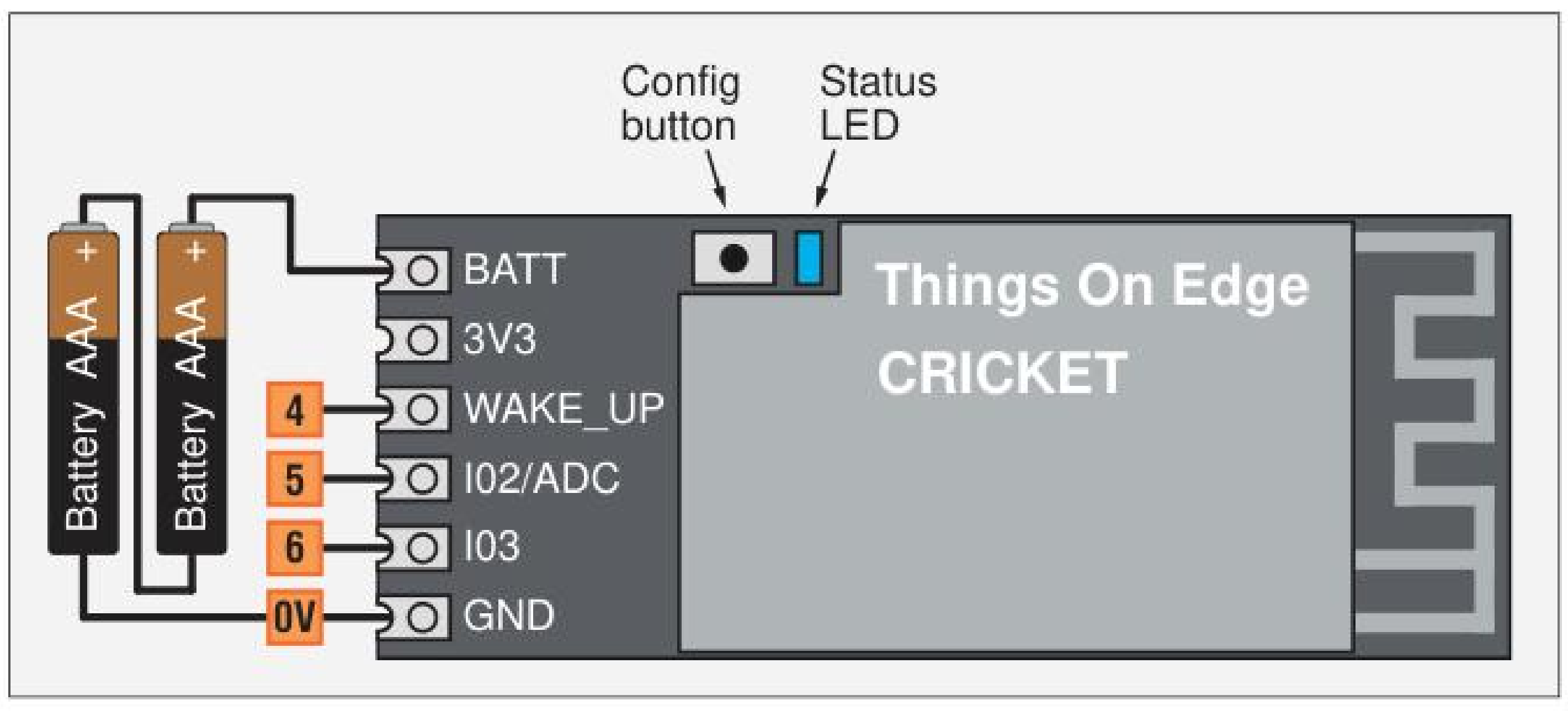


Fig.1. The Cricket has six pins, four of which are used when it's connected to the Micromite. In addition, a button is connected between Micromite pin 3 and 0V (not shown here).

point is, I want to demonstrate these 'building blocks' working together – and once they are, you can then simply replace the button (ie, the input), and the email notification (ie, the output) with literally any alternative combinations that your imagination allows.

To expand on this a little, consider being able to use a collection of different sensor modules (that could be any mix of I²C, SPI and UART hardware – something the Cricket can't currently handle). Whenever a particular condition occurs with the data from the sensors, you can then trigger various outputs such as a pop-up notification to your smartphone, as well as turn on various lights (or any other mains-powered device) in your home.

All this becomes possible by using the combination of just three building-blocks: the Micromite, the Cricket, and in this case, the IFTTT service. But before we get carried away, lets return to using a button to trigger an email.

Cricket pins

Referring to Fig 1, you can see that there are six pins on the Cricket. Their labels are self-explanatory, but to avoid any doubt, these six pins have the following functionality:

1. BATT	This is the battery power input (1V to 3.5V), typically one or two AAA/AA.
2. 3V3	This is an output. It can power external hardware while the Cricket is 'awake'.
3. WAKE_UP	A high on this input will wake the module (if sleeping). Note: this pin can also be used as a digital input (IO1).
4. IO2/ADC	Digital or analogue input.
5. IO3	Digital input.
6. GND	Ground supply.

The Cricket has been specifically designed to be powered from a battery. One (or ideally two) batteries can be used. Note that if you use a voltage regulator to supply power to the Cricket then it will behave erratically. Therefore, we will not be using the Micromite 3.3V output to power the Cricket. Fig.1 shows two 1.5V batteries in series – positive to the Cricket's BATT pin and negative to the Cricket's GND pin *and* the Micromite's 0V line.

Connecting the Cricket to the MKC

We will make four connections to the Cricket from the *MKC*. Note that we could have connected them together with just two wires (0V, and Wake_Up); however, we will also connect the Micromite to the Cricket's IO2 and IO3 pins for extra functionality.

Referring to Fig.1 (and as explained above), power is supplied from two 1.5V batteries connected in series; connected to the BATT and GND pins on the Cricket. Remember: the 3V3 pin on the Cricket is *not* a power input, it is a power output. Do *not* feed power into this pin – you will permanently damage the Cricket. You have been warned!

Micromite pin 4 (which will be set to an output) is connected to the Wake_Up pin. This will provide the capability to wake the Cricket from 'sleep' by setting pin 4 high in our program code (with the command `PIN(4)=1`), or more specifically, by pulsing pin 4 high (with the command `PULSE 4,10`).

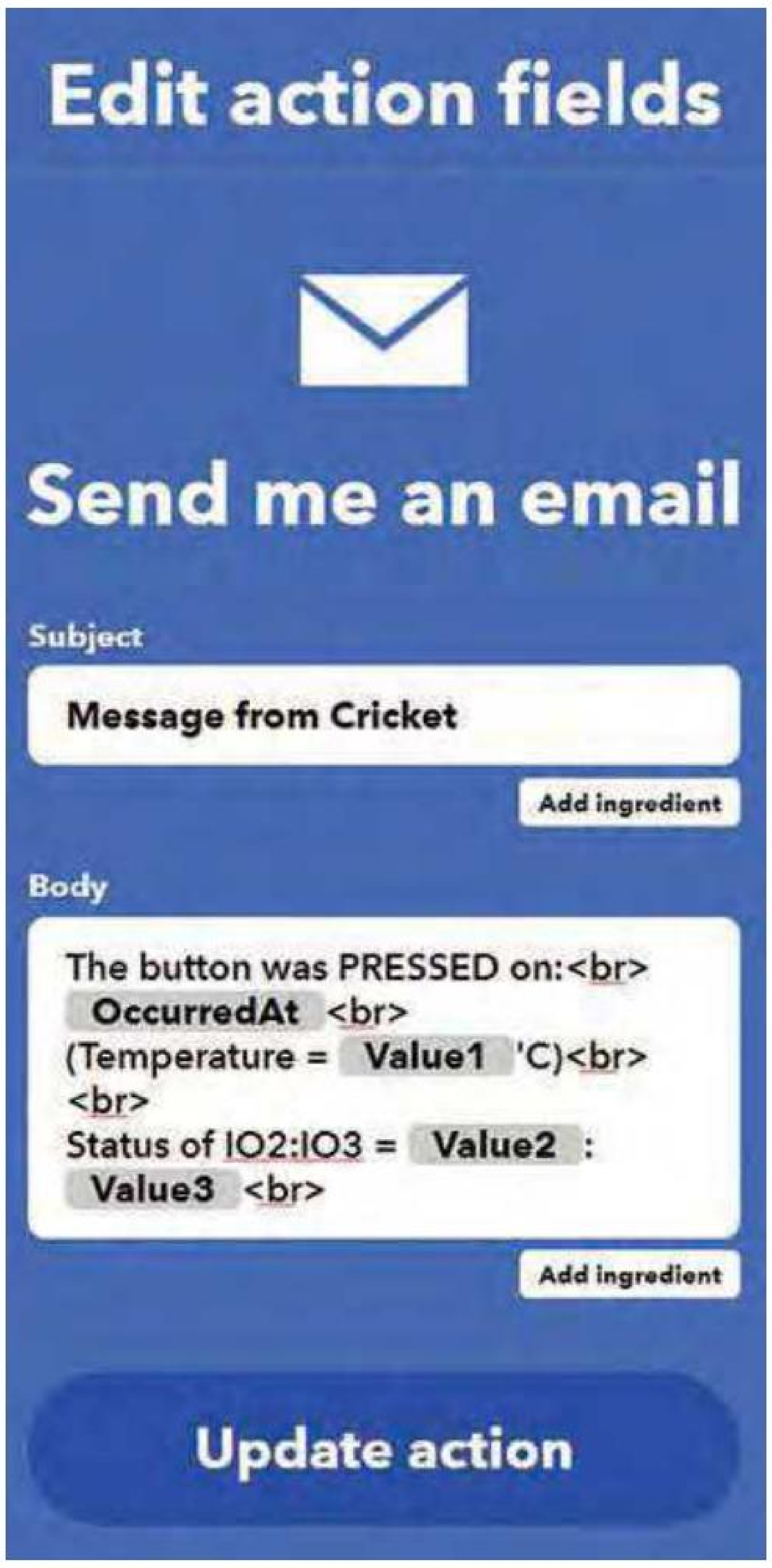
Pin 5 and Pin 6 on the Micromite (also set as outputs) are connected to the Cricket's two input pins, IO2 and IO3 respectively. These are optional, but they will be used to allow our program code to apply a logic level (0 or 1) so that these logic-level states can also be sent to the Internet. This arrangement effectively provides us with four possible combinations (00, 01, 10, and 11).

In addition to hooking up the Cricket, we also need to connect a button to the Micromite (the one that will trigger the email). If you don't have a button readily available, then simply substitute it with a switch. Whatever you use, it should be connected between 0V and any I/O pin (I chose pin 3).

Before writing any MMBASIC code, we first need to register for an IFTTT account (and also configure it to send an email), and afterwards we will have to set up the Cricket to connect it to our local Wi-Fi network and configure it to talk to IFTTT. Let's work through the first of these steps.

IFTTT

You can register for an IFTTT at: **https://ifttt.com**. If you already have an IFTTT account, then simply log in; otherwise complete the straightforward registration process using a valid email address. When you have logged into your account, you should see a screen similar to that shown in *Fig.2a* (if not, then click on the 'My Applets' link). Next, we need to configure an IFTTT applet to send an email. To do this, work through the following 18 steps. (Note: I have taken screen grabs to explain these steps, but there are 21 of them and there simply isn't room to show all the steps here. So, where there is reference to Fig.2 in plain text, I have included the screenshot in this article – all other references to Fig.2, in italics, are in a separate document that you can download from the August 2021 page of the *PE* website.)



Subject

Message from Cricket

Body

The button was PRESSED on:
OccurredAt
(Temperature = Value1 'C)

Status of IO2:IO3 = Value2 :
Value3

Fig.2m. Configuring IFTTT to send an email with the subject line 'Message from Cricket'.

1. Click the 'Create' button (black button, top-right corner) and you will see a screen similar to *Fig.2b*.
2. Click the 'Add' button next to 'If This' (*Fig.2b*).
3. In the 'Search services' box (*Fig.2c*), start typing `webhooks`. As you start typing, you will see the number of icons reduce.
4. Click the blue 'Webhooks' icon (*Fig.2d*)
5. Click the blue 'Receive a web request' block (*Fig.2e*)
6. In the 'Event Name' input box (*Fig.2f*), type `button_pressed`
7. Press the 'Create trigger' button (*Fig.2g*)
8. Click the 'Add' button next to 'Then That' (*Fig.2h*)
9. In the 'Search services' box (*Fig.2i*), start typing `email` until you see the 'Email' icon (*Fig.2j*)
10. Ensure you click on the 'Email' icon – not any other icon that may be visible (*Fig.2j*).
11. Click the blue 'Send me an email' block (*Fig.2k*).
12. In the 'Subject' input box (*Fig.2l*), clear the existing text, and then type `Message from Cricket` (see Fig.2m).
13. In the 'Body' input box, clear the existing text, and carefully type the text below. Bold text is entered by selecting the 'Add ingredient'

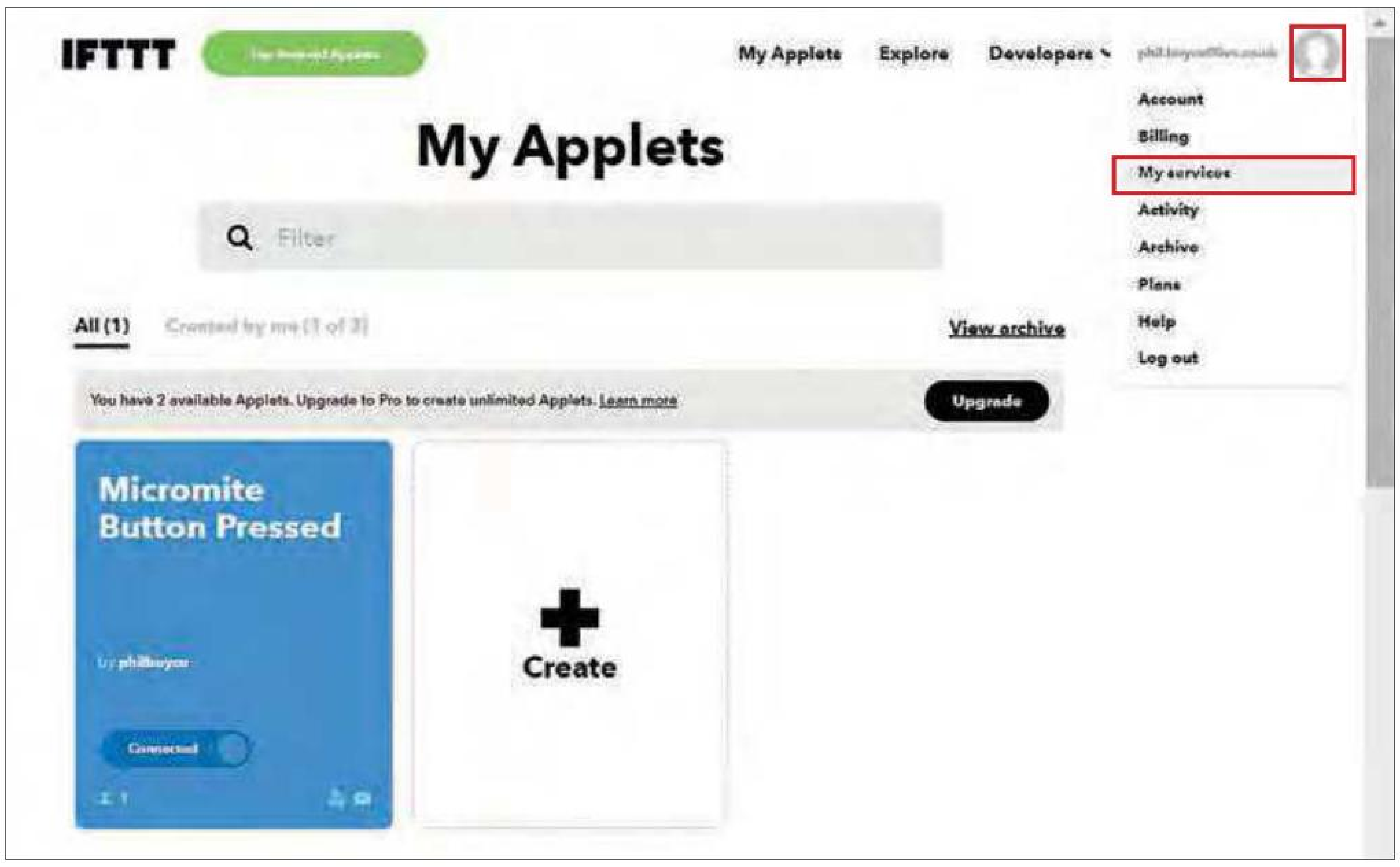


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Fig.2s. Choosing 'My Services' in IFTTT .

button. (Refer to Fig.2m):

```
The button was PRESSED on:<br>
OccurredAt<br>
(Temperature = Value1'C)<br>
<br>
Status of IO2:IO3 = Value2:
Value3<br>
```

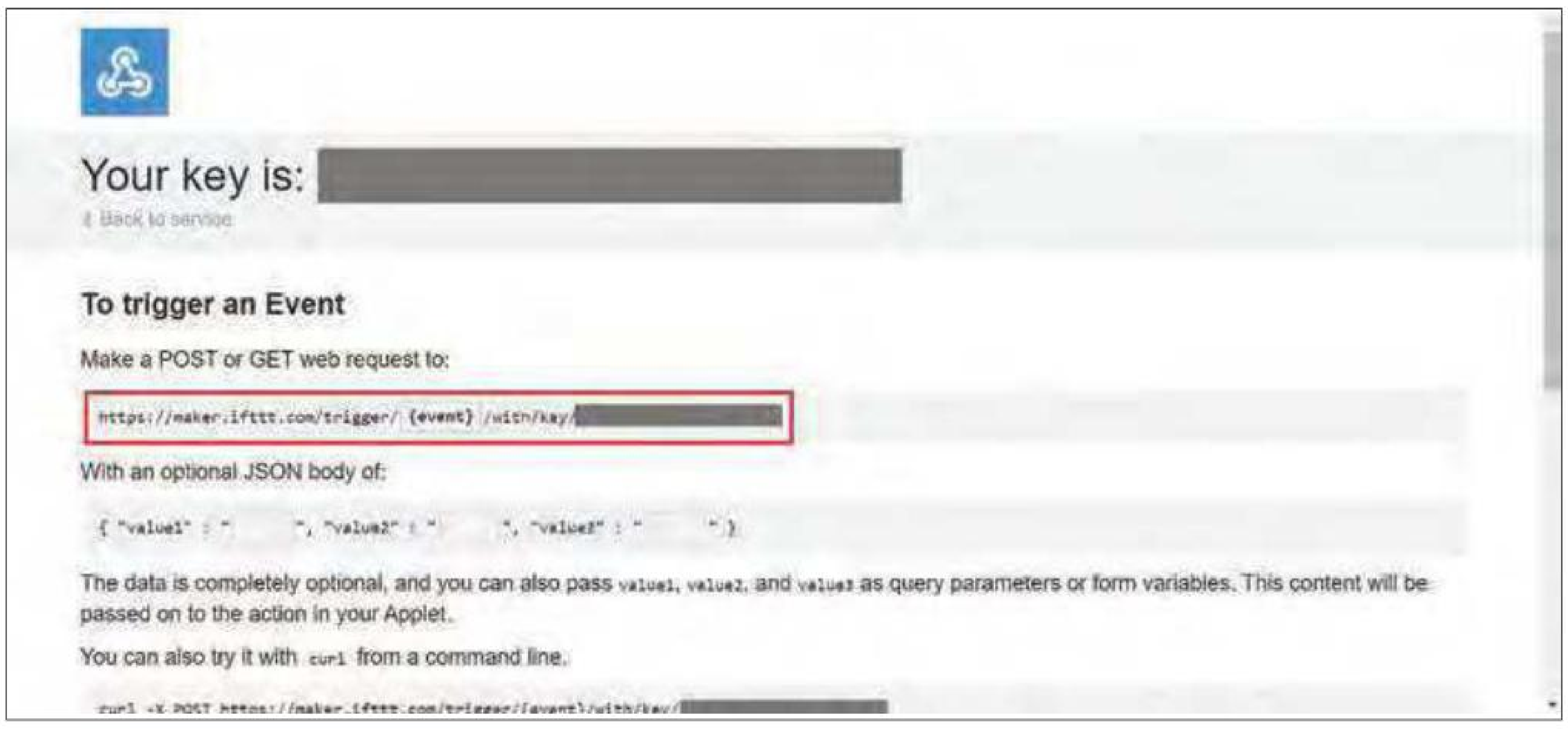
14. Click the 'Update action' button (Fig.2m).
15. Click the 'Continue' button (*Fig.2n*).
16. Click the 'Finish' button (*Fig.2o*).
17. Click the 'Edit title' link (*Fig.2p*), and change it to the shorter title, 'Micromite Button Pressed' (*Fig.2q*).
18. Click 'My Applets' link to see it in your list of Applets (*Fig.2r*).

Finally, you will need to obtain the HTTP address (created by IFTTT) which will be used to configure the Cricket. To obtain this, click on your user icon (top right corner next to the black 'Create' button), and select 'My Services' from the drop-down menu (Fig.2s). Then scroll down the list and click on 'Webhooks' (probably the last item in the list). This will result in *Fig.2t*, where you click on the 'Documentation' button (top-right corner). You will now see a screen similar to Fig.2u. Copy the HTTPS address shown under the heading 'To trigger an Event' (highlighted in red in Fig.2u) and paste it into something like Notepad (this information will be used shortly).

That concludes the IFTTT setup; next we need to configure the Cricket.

Configuring the Cricket

To configure the Cricket, it's worth referring to *PE* June 2021 (p.47) and looking at Steps 6-8. Essentially, you will need to power the Cricket (ideally, using a pair of AAA/AA batteries – as shown in Fig.1) and then press the Config button for approximately five seconds. Once the blue LED is flashing, the Cricket is operating as a wireless hotspot. Use your computer to search for local Wi-Fi networks and connect to the Cricket by selecting `toe_device` (see Fig.3, repeated from the PE June 2021 Cricket IoT article, Fig.15). No password is required to connect, and you will automatically be linked to the Cricket. The first time you do this you will be prompted to enter your local Wi-Fi SSID and password; and once entered, click the 'Connect' button. If the SSID and password were entered correctly you can now click on the 'Config' tab (see Fig.4) and carefully enter the following Cricket settings:



Your key is: [redacted]

Back to service

To trigger an Event

Make a POST or GET web request to:

`https://maker.ifttt.com/trigger/ {event} /with/key/`[redacted]

With an optional JSON body of:

`{ "value1" : "        ", "value2" : "        ", "value3" : "        " }`

The data is completely optional, and you can also pass `value1`, `value2`, and `value3` as query parameters or form variables. This content will be passed on to the action in your Applet.

You can also try it with `curl` from a command line.

`curl -X POST https://maker.ifttt.com/trigger/{event}/with/key/`[redacted]

Fig.2u. Copy this HTTPS address from IFTTT.

```
CONNECTIVITY
Type                 HTTP_POST
url                  *** see text below ***
payload              {"value1":"#temp","value2":
                     "#io2","value3":"#io3"}
content-type         application/json

RTC                  off
BATTERY MONITOR      off
TEMPERATURE SENSOR   on
averaging            on
avg num of points    8

IO1 force update     on
IO2                  on (DIGITAL_IN)
IO3                  on (DIGITAL_IN)

WI-FI enable caching on

CONFIG OTA           off
```

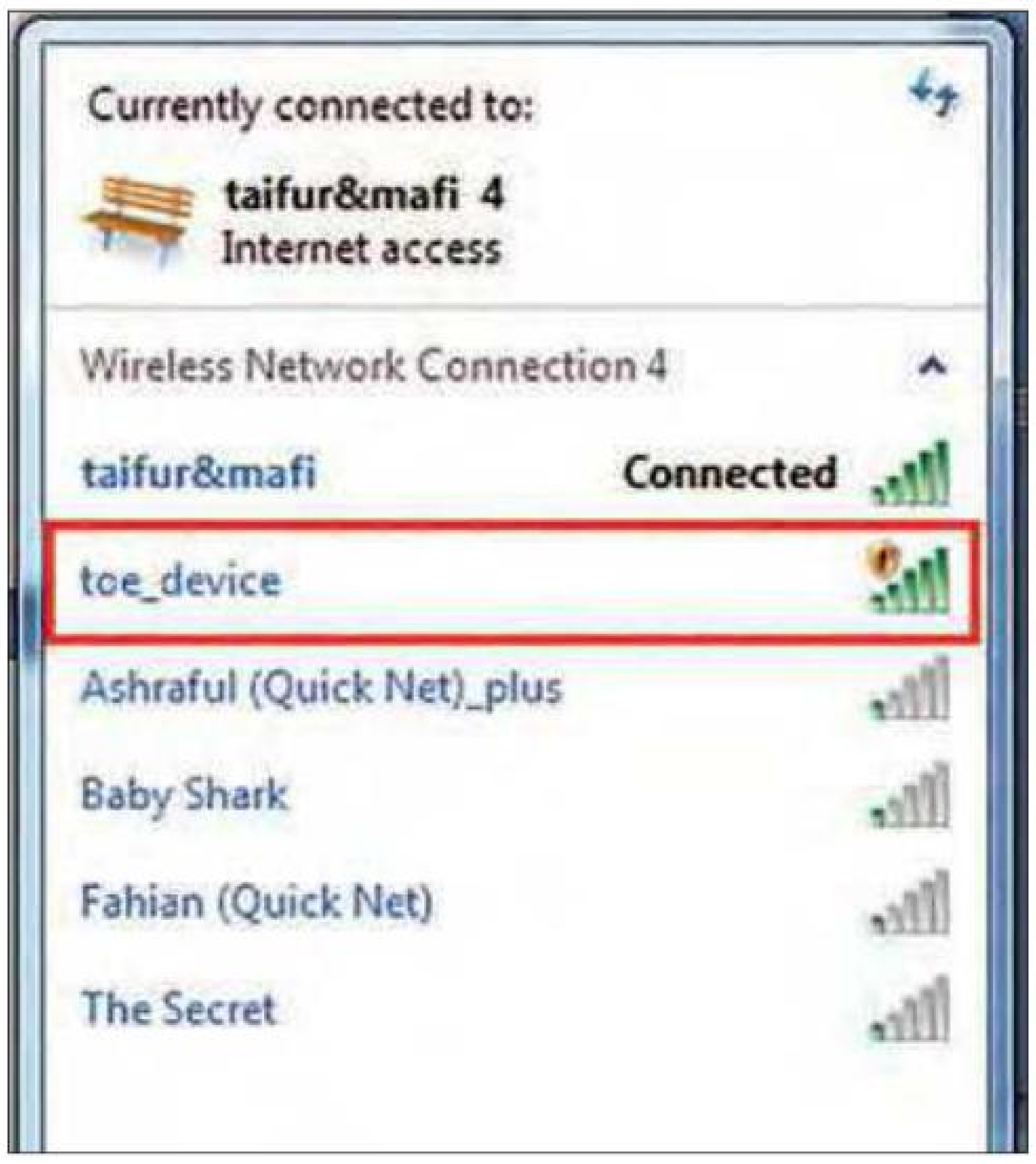
*** Regarding the URL, paste the HTTPS address obtained from IFTTT (and which we copied above into Notepad, or similar). Important: there are two things that must be edited:

- Change https to: `http`
- Change {event} to: `button_pressed`

The configuration for the URL should end up looking something like: **http://maker.ifttt.com/trigger/button_pressed/with/key/********************** (* replaced with your API key).

Once the above configuration has been entered correctly into the Cricket's 'Config' tab, ensure that the device status shows as UPDATED (this is in yellow under the STATUS heading, and can be seen in the top of Fig.4). Then press the 'power' icon located in the top-right corner of Fig.4. This will save all elements of the configuration data into the Cricket.

This concludes all the settings that are required. You can now download the **CricketDemo.txt** program from the August 2021 page of the *PE* website and load it into the Micromite so that we can finally test that everything works correctly.



Currently connected to:

taifur&mafi 4
Internet access

Wireless Network Connection 4

taifur&mafi Connected

toe_device

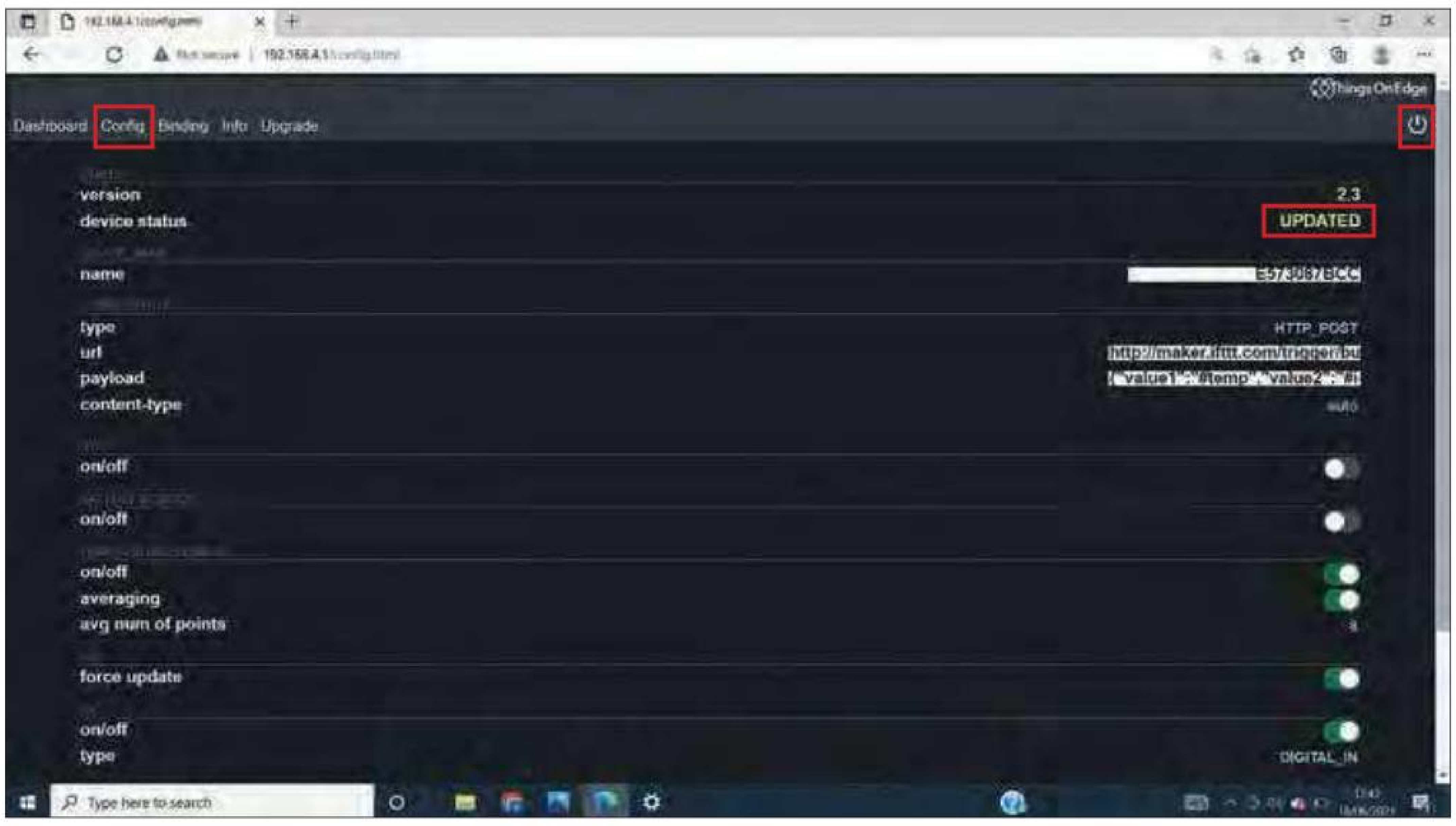
Ashraful (Quick Net)_plus

Baby Shark

Fahian (Quick Net)

The Secret

Fig.3. Select toe_device to connect your computer to the Cricket via Wi-Fi.

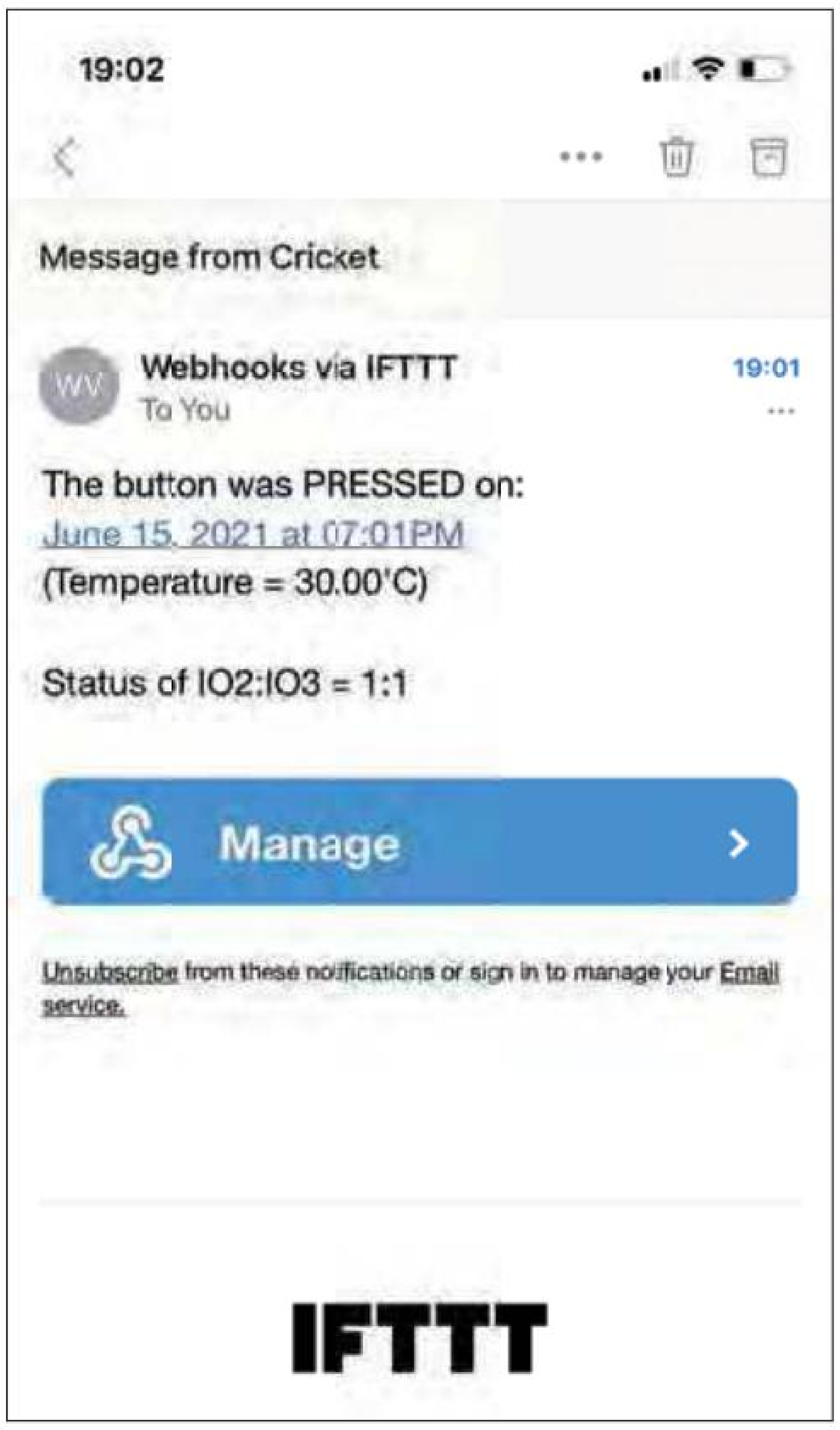


version 2.3
device status UPDATED
name E573087BCC
type HTTP_POST
url http://maker.ifttt.com/trigger/bu
payload {"value1":"#temp","value2":"#I
content-type auto
on/off
on/off
on/off
averaging
avg num of points 8
force update
on/off
type DIGITAL_IN

Fig.4. The Cricket Config screen.

Program code

With the **CricketDemo.txt** program loaded into the Micromite, `RUN` the program and then press the button connected to Pin 3. Upon pressing the button, you should see the blue status LED (on the Cricket) flash a few times. This indicates that the Cricket has woken and is sending data to the internet. If you do not see the blue status LED flash when the button is pressed, re-check that your button is connected correctly to pin 3, and also that the **CricketDemo.txt** program is running. Within around 10 seconds of pressing the button (and the status LED flashing), you should receive an email to the email address used when setting up your IFTTT account. If viewing the email on a smartphone, it will look something similar to that shown in Fig.5. If no email is received (but the Cricket's blue status LED did flash), then you will need to re-check the configurations in both the Cricket, and also your IFTTT Micromite Button Pressed applet.



Message from Cricket

Webhooks via IFTTT 19:01
To You

The button was PRESSED on:
June 15, 2021 at 07:01PM
(Temperature = 30.00'C)

Status of IO2:IO3 = 1:1

Unsubscribe from these notifications or sign in to manage your Email service.

Fig.5. The content of the received notification email (as viewed on a smartphone). The layout is as configured in the IFTTT applet, and the data values are passed from the Cricket (via the Internet) to IFTTT. As well as seeing the status of IO2 and IO3, the date and time of the button press is also shown, along with the temperature (yes, it really was 30°C).

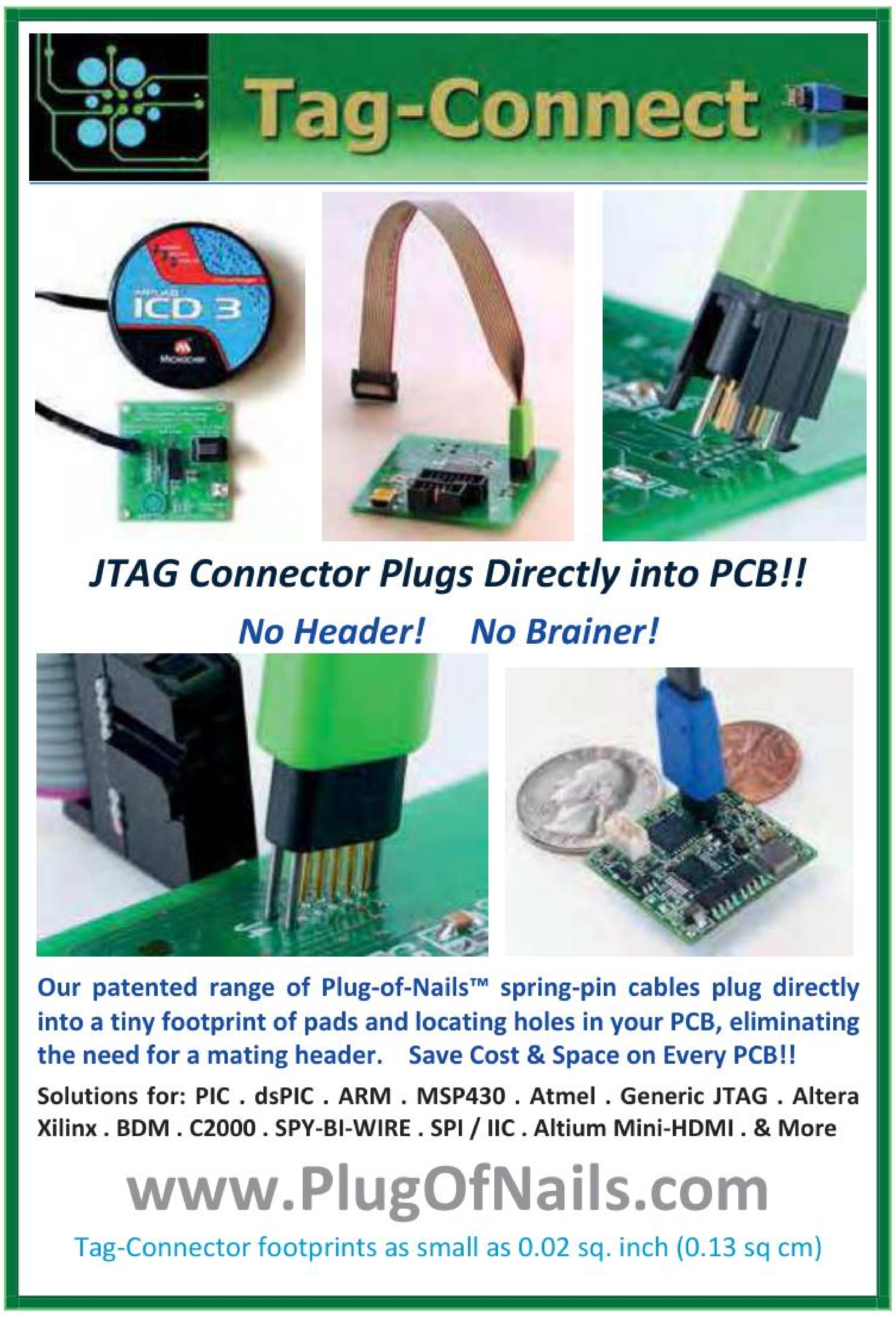
If everything has worked for you as expected, great! If not, and you're struggling to get it working correctly, then drop me an email and I will try to help.

It's well worth looking at the program code and making changes to alter the values of IO2 and IO3 (it will be fairly obvious how to do this, especially if you read the code comments).

That's it for this month, but why not have a play with IFTTT and see what other web services you could trigger instead of an email. If you are fortunate enough to have some Philips Hue lighting, why not try switching some lights on whenever the button is pressed. And how about replacing the button with a distance module instead, and trigger the output (lights, email, mains smart-plug…) based on the distance detected.

I hope this has inspired you to explore further, so until next month, have FUN playing Cricket!

Questions? Please email Phil at:
contactus@micromite.org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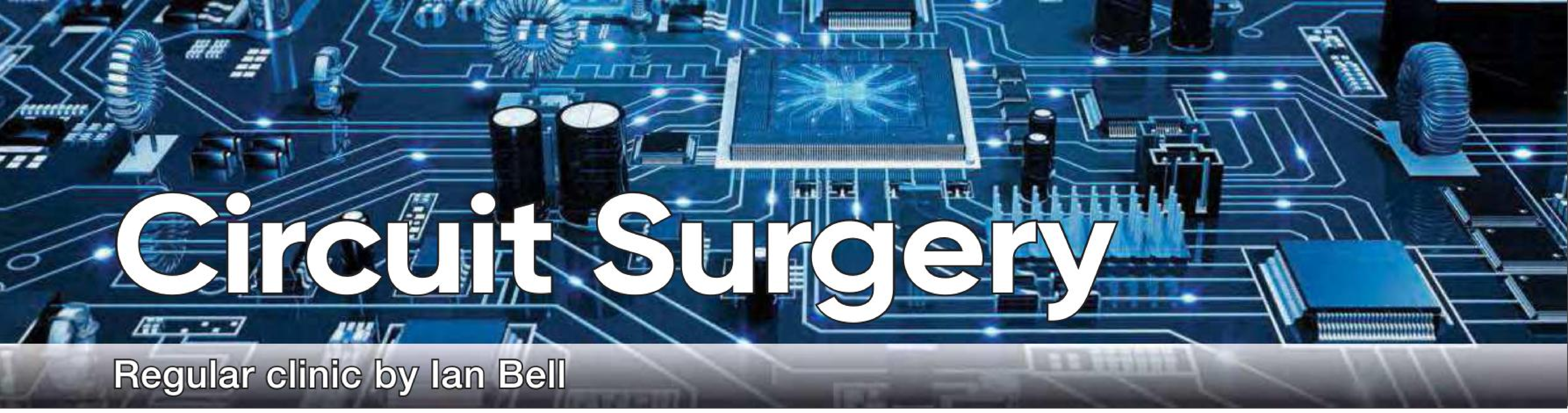


Circuit Surgery

Regular clinic by Ian Bell

Transformers and LTspice – Part 3

This month, we continue looking at the basics of transformers and some aspects of simulating transformer circuits in LTspice. The first article (June 2021) covered some general transformer concepts, the second (July 2021) looked at power supplies and this month we will conclude by considering some signal-processing applications. Key aspects of the use of transformers in signal processing are impedance matching and the use of balanced signals. We will discuss some basics related to matching and balanced signals as well as looking at the use of transformers in these contexts.

Recap: turns ratio

The relationship between the primary and secondary voltages and current for an ideal transform is determined by the turns ratio. For a primary voltage and current (v_p, i_p) applied to a winding with N_P turns, and a secondary with N_S turns the secondary voltage and current will be:

$$v_s = \frac{N_s}{N_P} v_p$$

$$i_s = \frac{N_p}{N_s} i_p$$

An *ideal* transformer is 100% efficient so the input power will equal the output, although *real* transformers are of course not 100% efficient.

Transformers comprise a set of coils, and coils on their own are inductors. Coil inductance (L) is related to the number of turns squared (N^2), but the specific relationship depends on their type, structure and dimensions. In general, we can write $L = kN^2$ so $N = \sqrt{(L/k)}$, where k is a constant. For an ideal transformer we can assume k is the same for the primary and secondary windings, so:

$$v_s = \sqrt{\frac{L_p}{L_s}} v_p$$

The turns ratio is equal to the square root of the inductance ratio of the windings (considered as individual inductors). This inductance ratio is important for setting up transformers in SPICE simulations.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

Reflected impedance and transformer model

As mentioned in the first article, transformers reflect impedances from one winding to another (Fig.1). For example, if we connect a load resistor (R_L) across the secondary then a circuit driving the primary will see an effective resistance (R'_L). The reflected resistance is determined by the square of the turns ratio, so in this case:

$$R'_L = \left(\frac{N_p^2}{N_s^2}\right) R_L$$

For an ideal transformer, in this example, the resistance 'seen' at the primary is just R'_L, but real transformers have some winding resistance (also called 'DC resistance' to distinguish it from effects such as leakage inductance). The secondary DC winding resistance (R_{WS}) will appear in series with R_L and be reflected into the primary in the same way. The primary DC winding resistance (R_{WP}) will be in series with the total reflected resistance. If the secondary is shorted (so $R'_L = 0$) then the primary will be seen as just the reflected secondary plus primary winding resistance. For example, for a 1:1 transformer with both windings having 100Ω DC resistance, the primary will look like a 200Ω resistor with the secondary shorted. Despite being constructed using coils, if the only imperfection is DC resistance, a transformer with a load resistor on the secondary will behave like a resistor, but real transformers have more characteristics than just DC winding resistance.

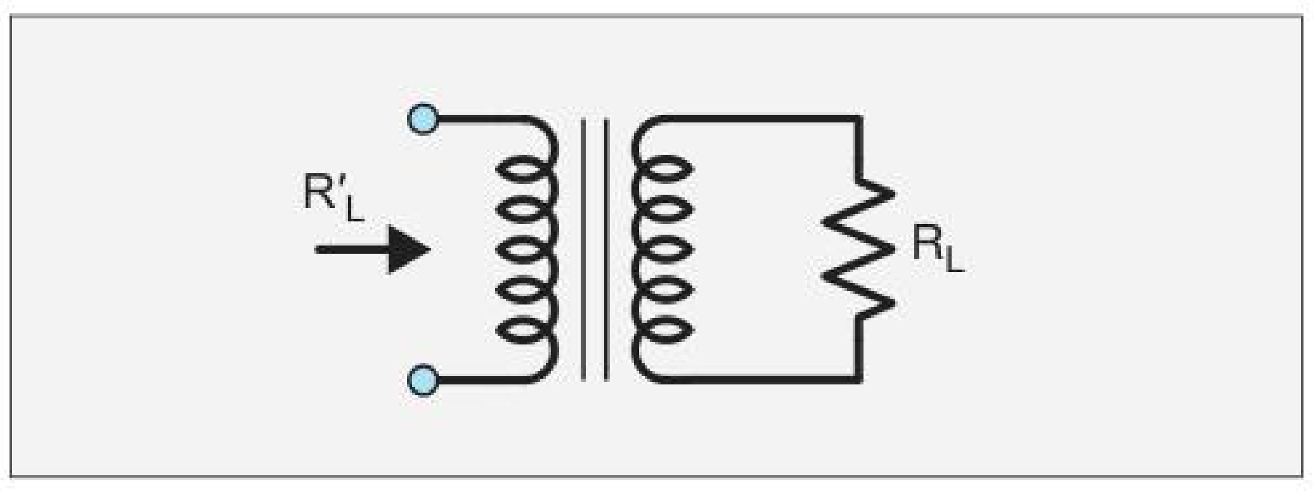


Fig.1. Reflected impedance.

If the secondary is open circuit, then the primary of a real transformer appears (can be modelled) as an inductor (L_M) in parallel with the (idealised) primary winding and in series with the primary winding resistance (see Fig.2) – so it does not behave as an open circuit on the primary side. This inductance is called the 'magnetising inductance'. In non-open-circuit situations its impedance may be sufficiently large to have little effect on the total impedance seen at the primary (if it is in parallel with a much smaller R'_L). Having mentioned magnetising inductance it is worth pointing out that another non-ideal inductance used to model real transformers is the leakage inductance, which is in series with both windings (L_{LS} and L_{LP}) – this accounts for the less-than-perfect flux coupling between the two windings.

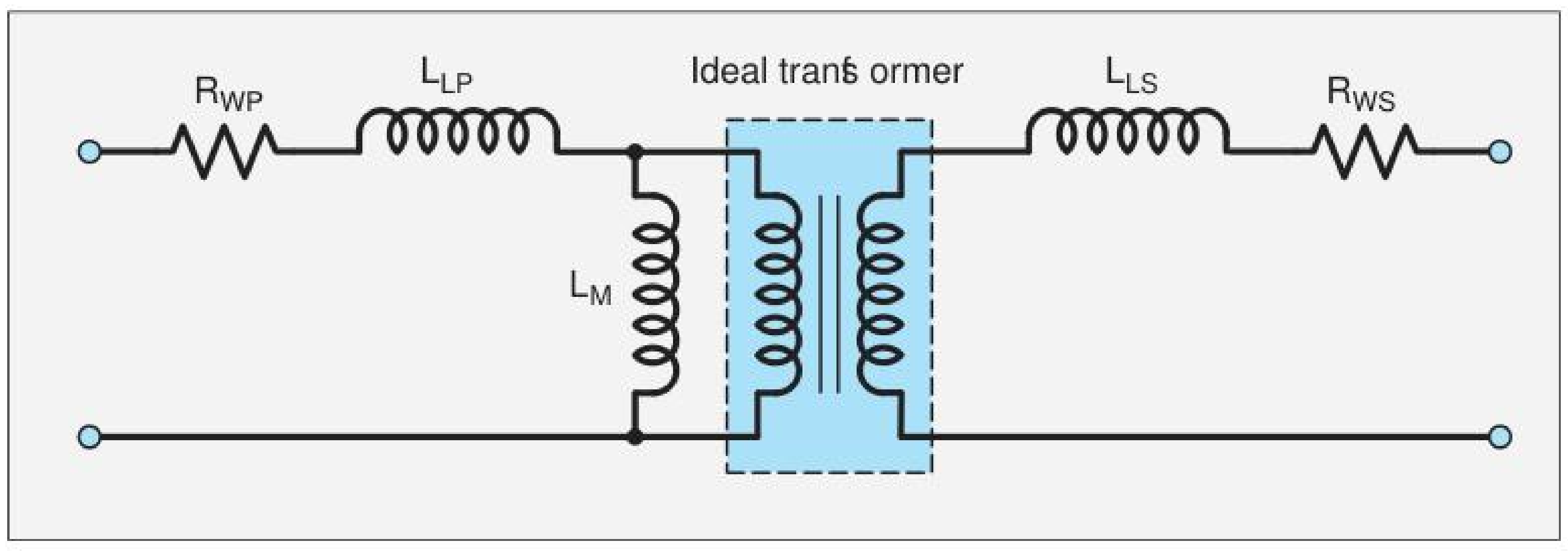


Fig.2. Simplified electrical model of a transformer.

Matching

The fact that a transformer can change the effective impedance of a load is a useful property which can be exploited in situations where the values of source and load do not provide workable or optimal circuit performance, but are difficult or impossible to change directly. We will look briefly at the relationships between source and load to help understand the role transformers

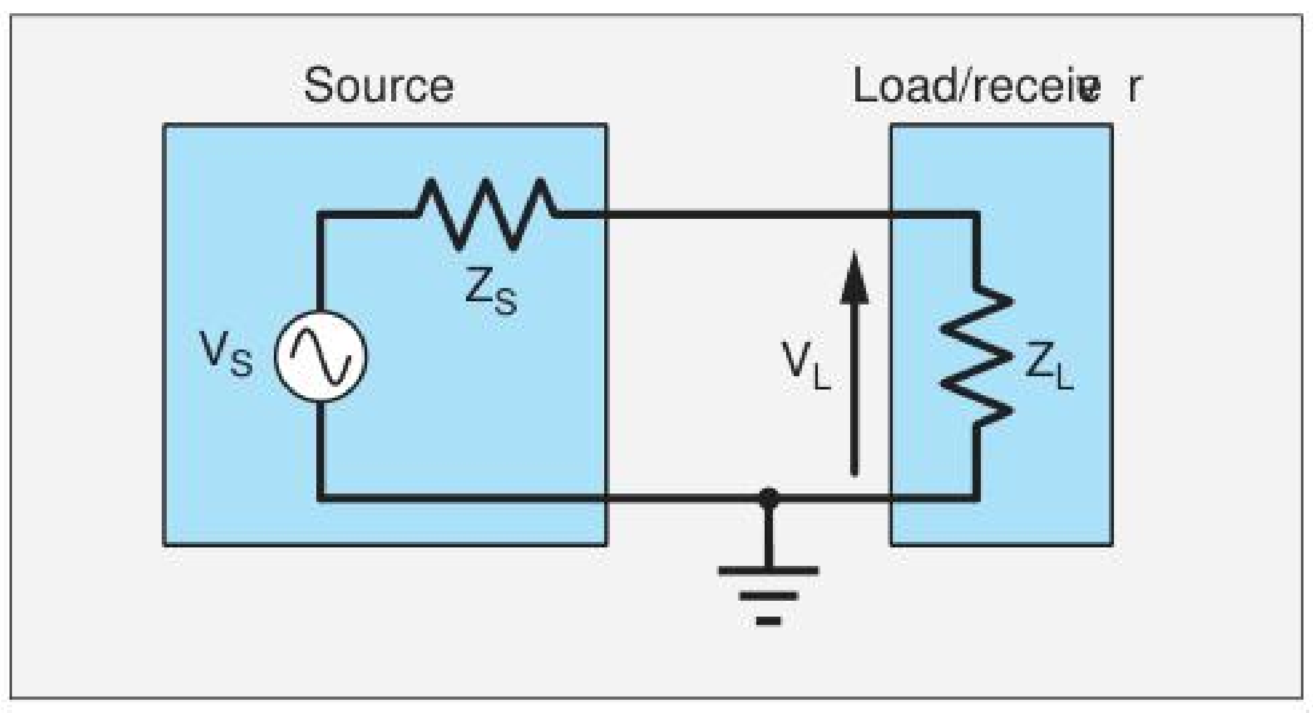


Fig.3. Source and load connected together.

can play in such situations.

Consider a source with impedance Z_S connected to a load of impedance Z_L, as shown in Fig.3. The two impedances form a potential divider. Thus, the voltage across the load is given by:

$$V_L = \frac{Z_L}{(Z_S + Z_L)} V_S$$

If $Z_S = Z_L$ we say that the source and load are 'matched'; under this situation maximum *power* is transferred from source to load (in order to prove this, you have to use calculus). This is sometimes, but not always what is required – often, however, we want to maximise the *voltage* at the load rather than the power transfer. If we want V_L to be as large as possible then Z_L must be much larger than Z_S (we are assuming Z_S is fixed). If Z_L is very much larger than Z_S then the load voltage is effectively equal to the source voltage. This situation, with high input / load impedance and low output impedance is sometimes called 'voltage matching'.

Transmission lines

The circuit in Fig.3 shows two systems interconnected by two wires – this represents a generic situation with a signal wire and return path where typically the return path is the earth or ground connection in the system. The situation could apply to a wide variety of situations including twisted pairs or coaxial cable, or to a single trace and ground plane on a printed circuit board. As drawn, the interconnections imply perfect simple conductors, but this is not the case in a real circuit where the wire will have some resistance and inductance and there will be capacitance, and possibly insulation 'leakage' resistance between them, particularly if they conductors are close together.

At low frequencies we could model such imperfections using single components, but lumping the capacitance (and other properties) of the cable into a single component model may not provide an accurate picture of how wiring behaves when a signal is applied. It all depends on the timescales which apply to the situation we are working with. If our signal cycles times, pulse durations, or circuit timescales in general, are less than, or comparable with the time taken for the signal to travel down the wire then the effect of signal propagation time means we have to consider the interconnection as a transmission line on which the signal propagates as a wave. Transmission lines (Fig.4) have a characteristic impedance (Z_0) which is related to the inductance and capacitance per unit length of the connection. If a transmission line is connected to or from a source or load whose impedance is different from Z_0 then wave reflections occur. These reflections damage the integrity of the signal and must be avoided – the output, line and input impedances must be matched. As a rule of thumb, we have to take account of transmission lines effects when the length of a connection is more than about one tenth the wavelength of the signal. The wavelength is given by $F_v c/f$, where f is the frequency, F_v is the velocity factor of the transmission line and c is the speed of light. For a connection with velocity factor of 0.5 this is 1.5km at 10kHz, 15m at 1MHz and just 15mm at 1GHz.

Transformer for matching

In summary, we may need to to:

- Match source impedance to a load for maximum power transfer
- Increase the effective impedance of a load or input where the source impedance is relatively high
- Match inputs and outputs to transmission lines
- Connect transmission lines of different characteristics to together.

A range of techniques are applicable, but in some situations, transformer-reflected impedance can provide the solution. If we have a transformer with an N:1 ratio, as shown in Fig.5, then the source sees the load impedance as $N^2 Z_L$. The reflection works both ways – we can also say that the load sees a source of impedance Z_S/N^2 with the transformer in place.

For example, if we had a high impedance source, with R_S = 100kΩ, and needed to drive a load of 1.5kΩ then an 8:1 transformer would reflect the load as 1.5 × 8² = 96kΩ, providing a much better match. This may be more about providing a load that the source is capable of driving, rather than exactly matching impedance, as is required for transmission lines. Specific examples of using transformers to modify effective impedance include microphone output transformers, PA system loudspeaker transformers and 300Ω-to-75Ω coaxial matching transformers. The latter requires a 2:1 turns ratio to achieve the 300:75 = 4:1 impedance ratio.

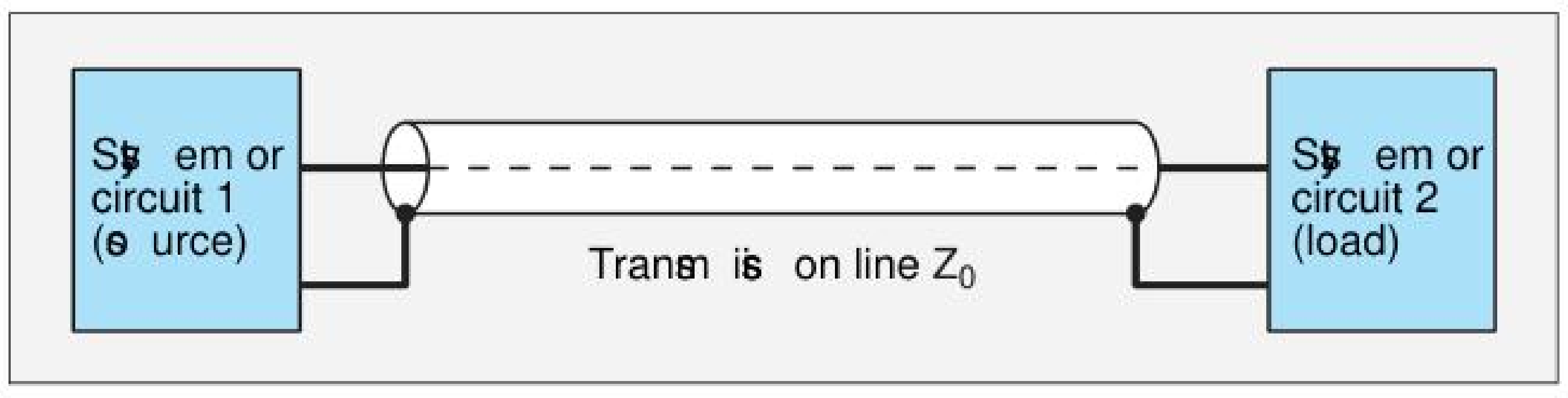


Fig.4. Transmission line model of a connection between two systems – if transmission line effects are presented then matching must be used.

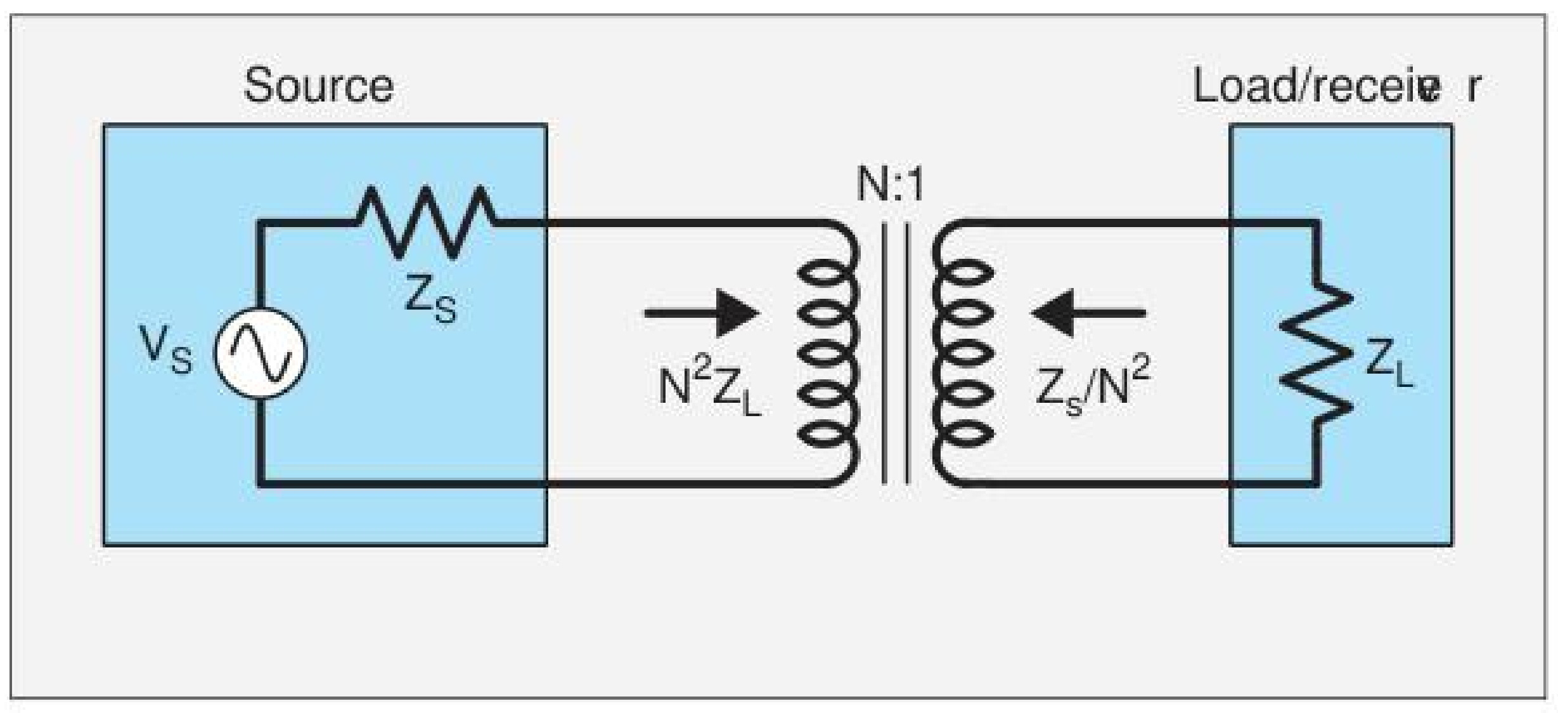


Fig.5. Transformer used to match source to load.

Balanced and differential signals

Returning to Fig.3, it shows a signal connection between two circuits, devices, or systems where the signal is carried on a single wire plus a ground connection. This is a single ended, unbalanced connection. The term 'unbalanced' refers to the fact that there are unequal impedances with respect to ground at both the input and output – obviously, the ground wire has very low, ideally zero impedance with respect to ground, whereas for the output and input the impedances to ground are related to Z_S and Z_L.

Ground connections are not perfect conductors, so any unwanted voltage difference between the grounds at each end (noise voltage V_N in Fig.6) will affect the voltage input at the receiving system / load. With the single connection in Fig.3 (modelled as a single copy of Fig.6) it is not possible to remove this noise. The solution is to carry the signal on two wires with both having equal impedances with respect to ground at all points (modelled as two parallel copies of Fig.6 with the same Z_S and Z_L). Because the impedances are equal on the two wires the overall connection is referred to as 'balanced'.

With a balanced connection we effectively have two parallel copies of the circuit in Fig.6. The ground is common to both, so the same V_N will affect both connections – we refer to this as 'common-mode noise'. Looking at Fig.6 and taking a reference point at the input ground, considering just

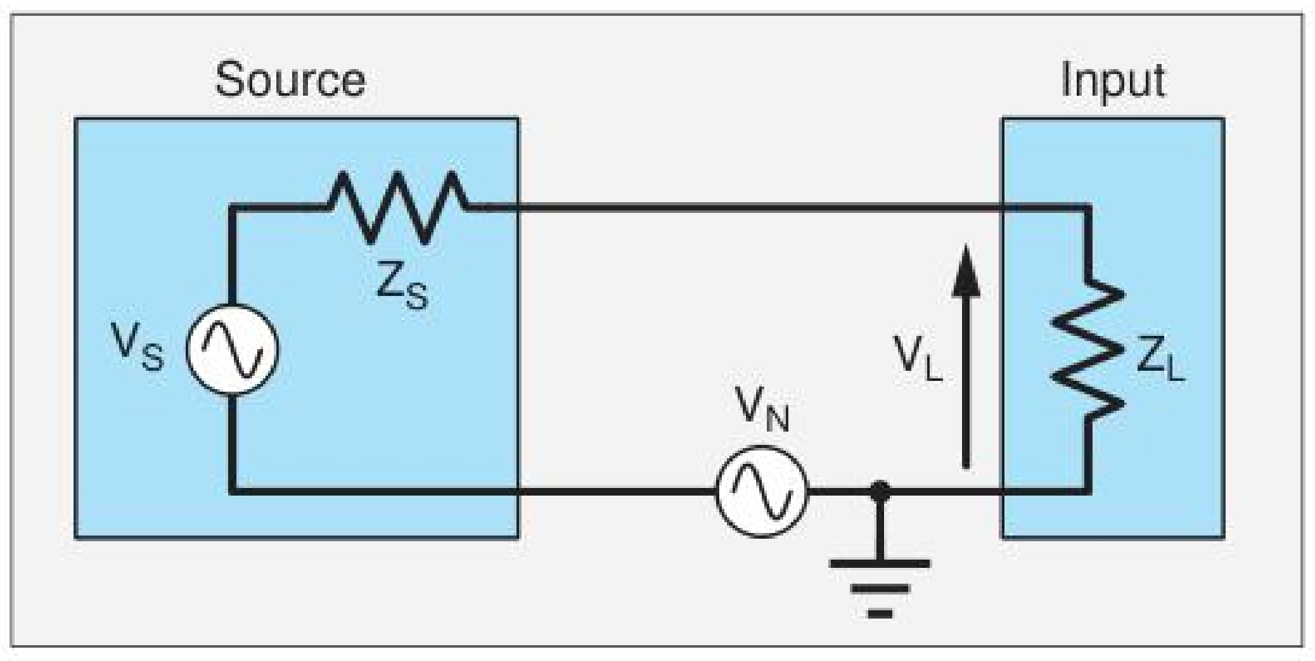


Fig.6. Connection with ground noise.

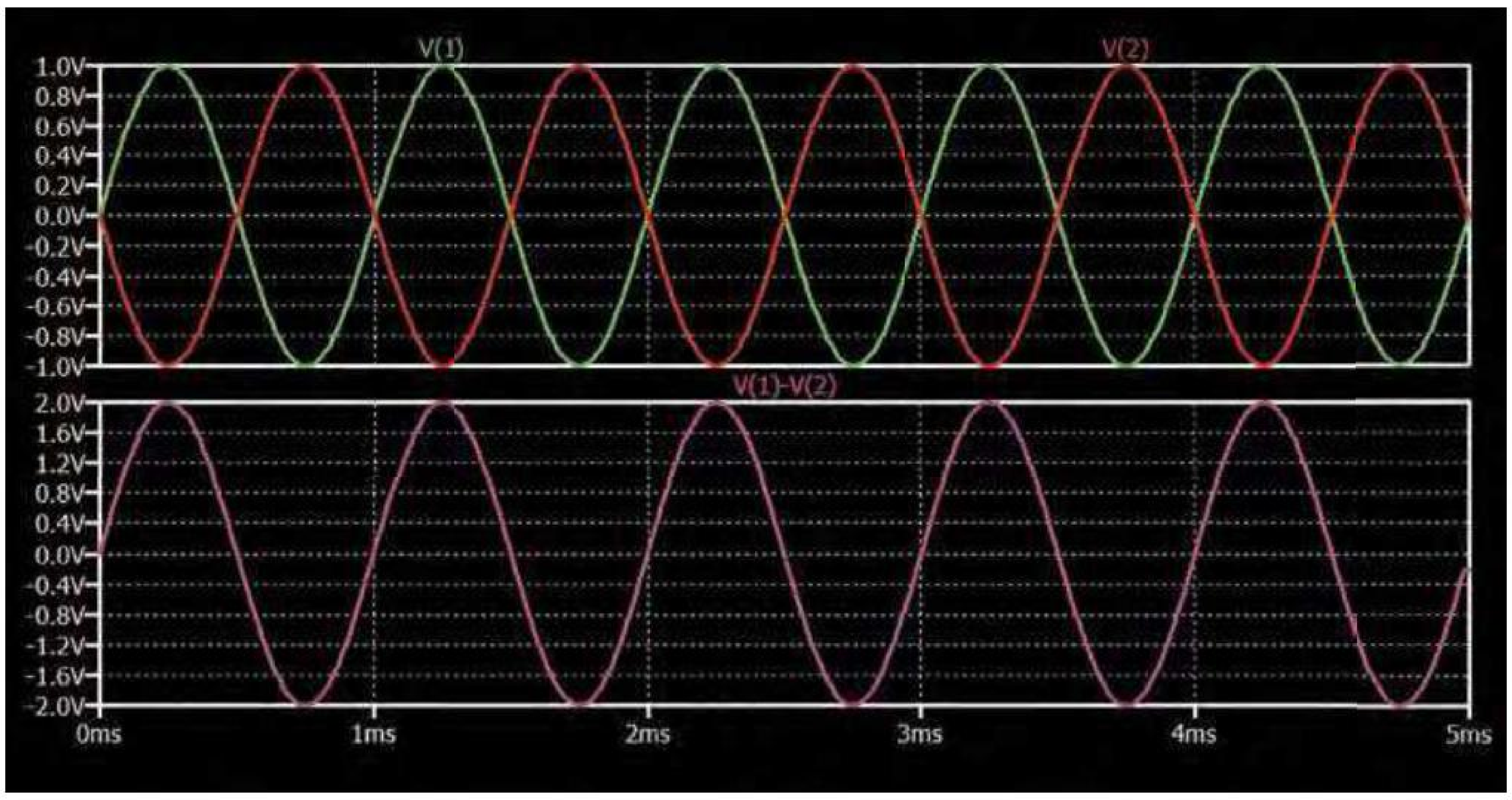


Fig.7. Differential signal – the voltages on the two individual wires V_1 and V_2 are shown in the upper plot. The actual signal is the difference between V_1 and V_2, as shown in the lower plot.

V_N (assume $V_S = 0$): Z_S and Z_L form a potential divider with respect to V_N, which results in some noise voltage at the input. If the impedances are the same in both copies then the noise voltage at both inputs will be the same. If the received signal or load voltage is taken as the difference between the two signals then the noise voltages at the two inputs will cancel out. Thus, a balanced connection can significantly reduce noise. If the impedances are perfectly balanced, and the difference between the two signals is taken perfectly, then the noise will be removed completely. Of course, this perfection is not possible in a real system, so the degree to which noise is removed is expressed as the common-mode rejection ratio (CMRR).

Interconnection options

There are two commonly used options for how the two wires in a balanced connection are used. One is to carry the actual signal on just one of the wires, with the other being 0V – equivalent to ground in (ideal) voltage terms but not in terms of impedances. The other approach is to use a differential signal where the two wires carry equal and opposite voltages. Fig.7 shows a differential signal which is a 1kHz sinewave with a peak voltage of 2V (4V peak-to-peak). The two individual voltages (V_1 and V_2 on the two wires that carry the signal) are shown on the upper plot – these are equal and opposite and have peak voltages of 1V. Because they are opposite, the peak difference between them is 2V, which is the amplitude of the differential signal. The signal itself is shown on the lower plot – this is $V_1 - V_2$.

It common for the original and final signals to be unbalanced, but balanced connections are used in situations where relatively long wires are required. Typically, these connections are also physically constructed to help reduce noise (eg, use of twisted pairs and shields). Fig.8 shows the three connection scenarios just discussed – unbalanced single-ended, balanced single-ended, and balanced differential. Fig.8 shows balanced signals being handled by differential amplifiers (differential input or output as required). This approach is commonly used, but transformers can also be used to convert between balanced and unbalanced signals, with a basic example shown in Fig.9. Transformers used for this purpose are often referred to as 'baluns'.

Transformer examples

Fig.10 shows an LTspice circuit to illustrate how a transformer converting a balanced (`bal1`, `bal2`) to unbalanced (unbal) signal removes common-mode noise. The balanced 250mV 1kHz signal is generated by `V1`, which has low output resistance of 1Ω each side. The ideal transformer is inherently symmetrical so there is no imbalance here. The common-mode noise takes the form of a 20mV 50kHz signal generated by `V2`. Using a centre-tapped transformer allows this to be added equally to the two signals, as would happen with ground noise in a real system – the noise can be seen in the upper plot plane in the simulation results in Fig.11. The lower plot plane shows the output signal on the secondary of the transformer – the 1kHz signal is present without any noise.

The two aspects of the use of signal transformers discussed so far can be combined – that is a transformer can be used to simultaneously provide balanced/unbalanced signal conversion and impedance conversion/matching. However, the transformer may not always

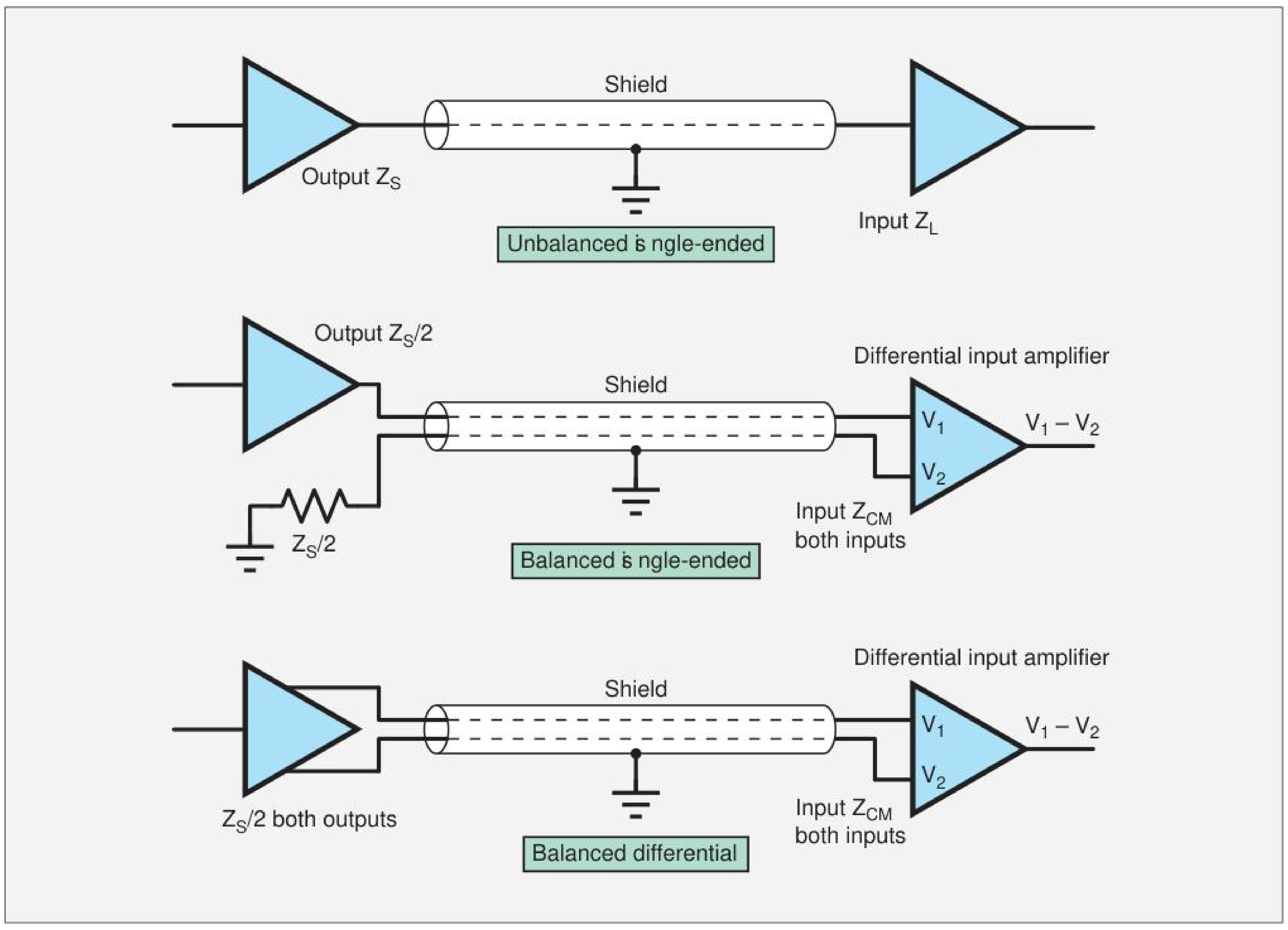


Fig.8. Balanced and unbalanced connections.

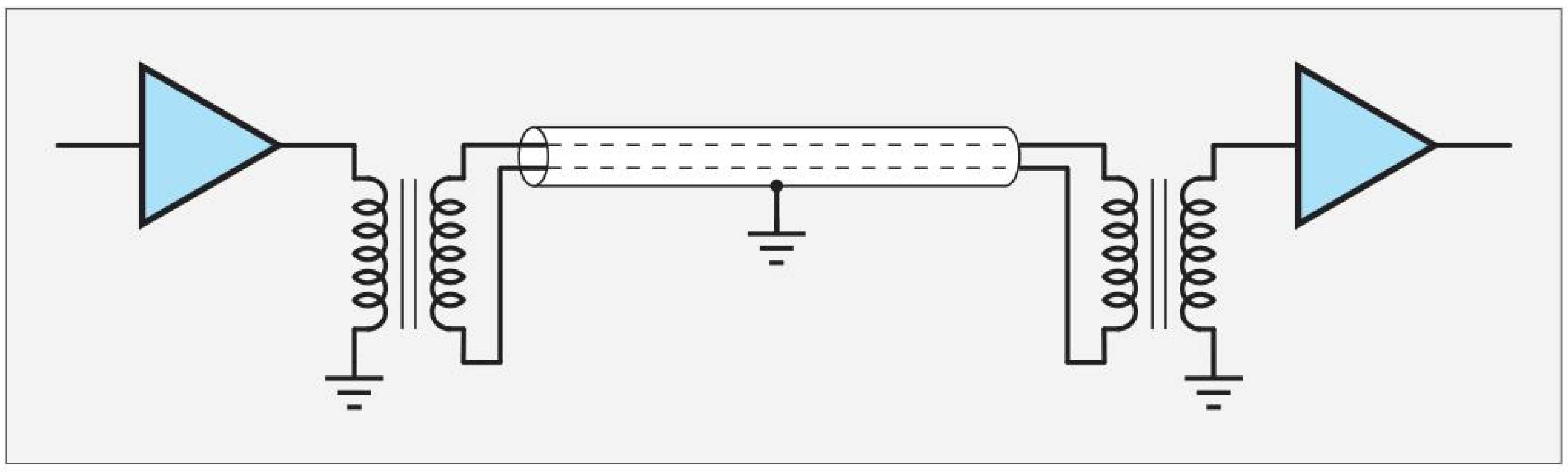


Fig.9. Using a transformer to create a balanced connection.

be used to (or be able to) provide full matching, but it must be taken into account. For example, if a 50Ω line (eg, coax cable) is connected to a transformer input the reflected impedance of what is connected to the secondary must be taken into account when terminating the line. Fig.12 shows a 50Ω line driving 500Ω via a 1:1 transformer. The reflected 50Ω in parallel with the 55.6Ω resistor provides a combined input impedance of 50Ω (1/55.5 + 1/500 = 1/50) to correctly terminate (match input impedance to) the line.

The discussion so far can apply to a variety of circuits. Transformers are used in both audio and radio frequency circuits. Balanced/unbalanced conversion is commonly used on the inputs of high-frequency analogue-to-digital converters (ADCs) with differential inputs and the outputs of digital-to-analogue converters (DACs) and direct digital synthesis (DDS) ICs.

As is usually the case, design of high-performance circuit is limited by the non-ideal characteristics of components. The previous discussion on the transformer model in Fig.2 gave some hint of this. This model can be redrawn in symmetrical form (sharing the series resistance and inductance between two connections of the primary and/or secondary) to accommodate use with balanced circuits. However, Fig.2 is far from the whole story. For example, there is capacitance across the windings and between the secondary and primary. This, together with the inductance and resistance leads to complex frequency-dependent behaviour which limits the bandwidth over which a transformer can be used and may require additional components to be connected to achieve the required characteristics from the circuit as a whole (eg, specific resistors across the transformer).

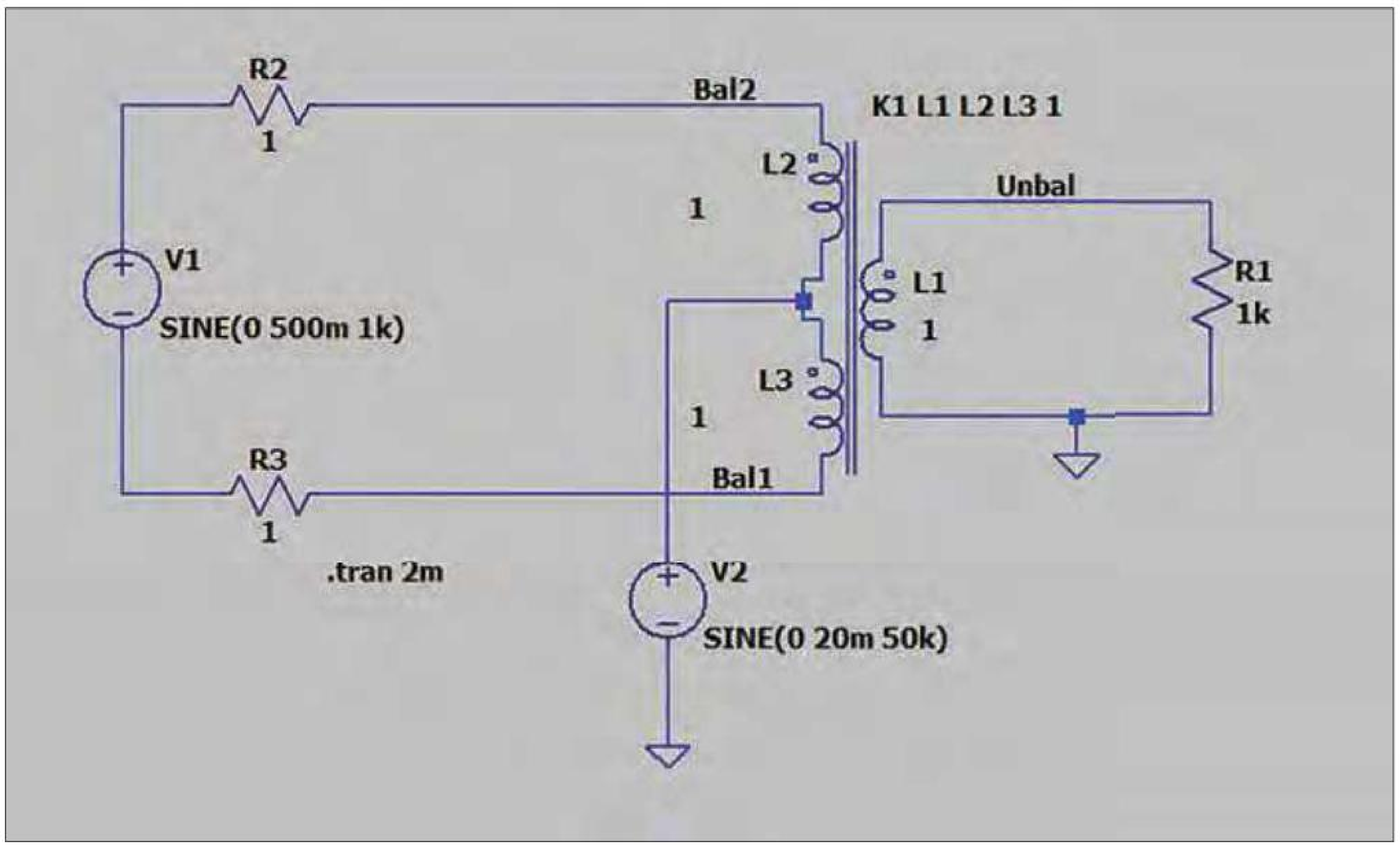


Fig.10. LTspice schematic for balanced-to-unbalanced signal conversion.

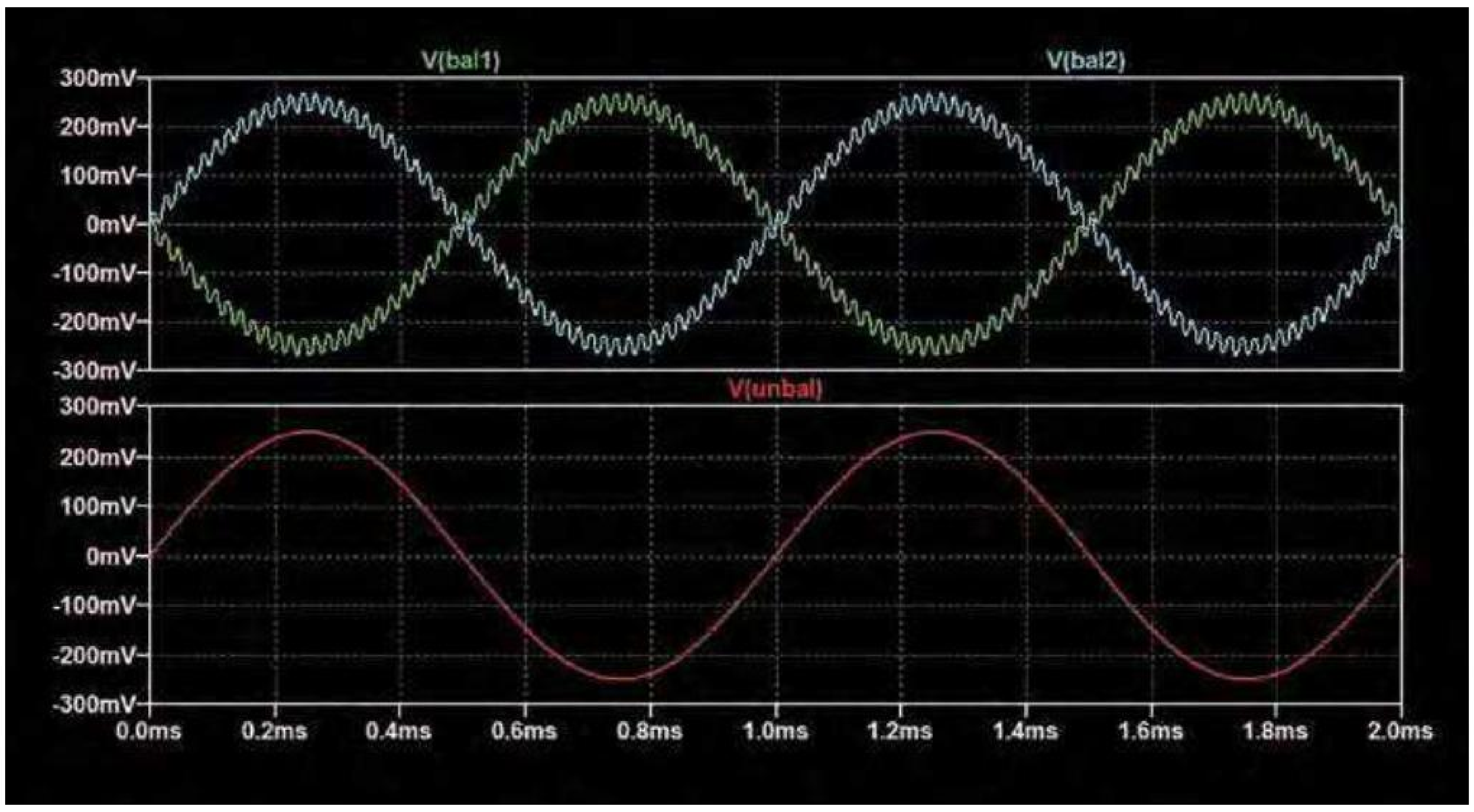


Fig.11. Simulation results for the circuit in Fig.10.

Phantom power

Finally, a specific and well-known use of transformers in audio is as part of the phantom power circuit used with condenser microphones with built-in preamplifiers. The circuit enables power to be delivered to the preamplifier over the same wires used to convey the signal. A simplified phantom power circuit is shown in Fig.13. The preamplifier unbalanced output is converted to a balanced signal by the transformer and conveyed to the audio system in this form via the microphone cable, which has two signal conductors plus a shield.

The power (typically 48V) is connected to both signal wires via a couple of resistors – thus it appears as a common-mode signal on the balanced line and can be obtained from the centre-tapped secondary of the transformer. Given that the balanced output here is a differential signal, the signal voltage at the centre tap is zero and so the preamplifier power supply, taken from the centre tap only sees the DC power – there is no signal fed to the amplifier supply. The shield is used as the return path for the DC power to the preamplifier.

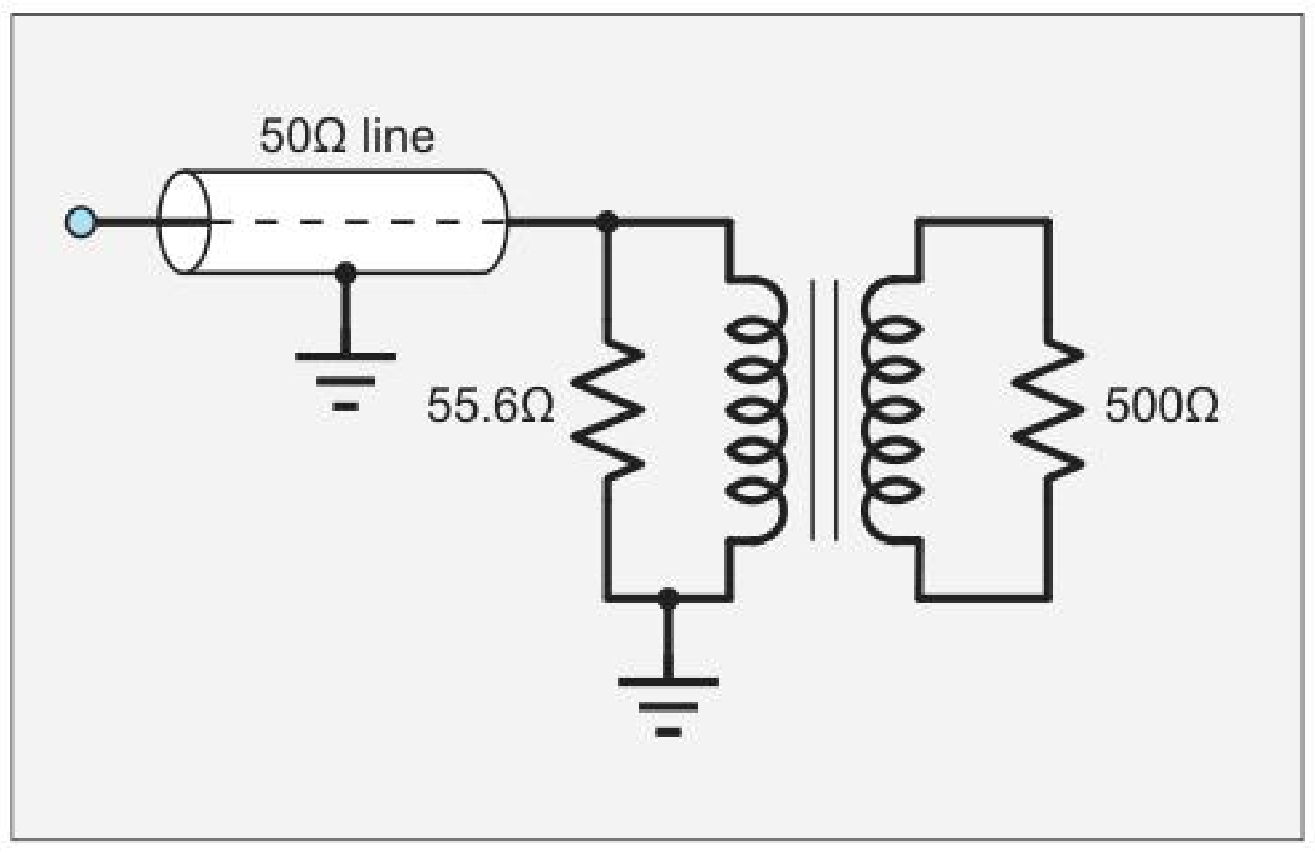


Fig.12. Example line termination taking reflected impedance into account.

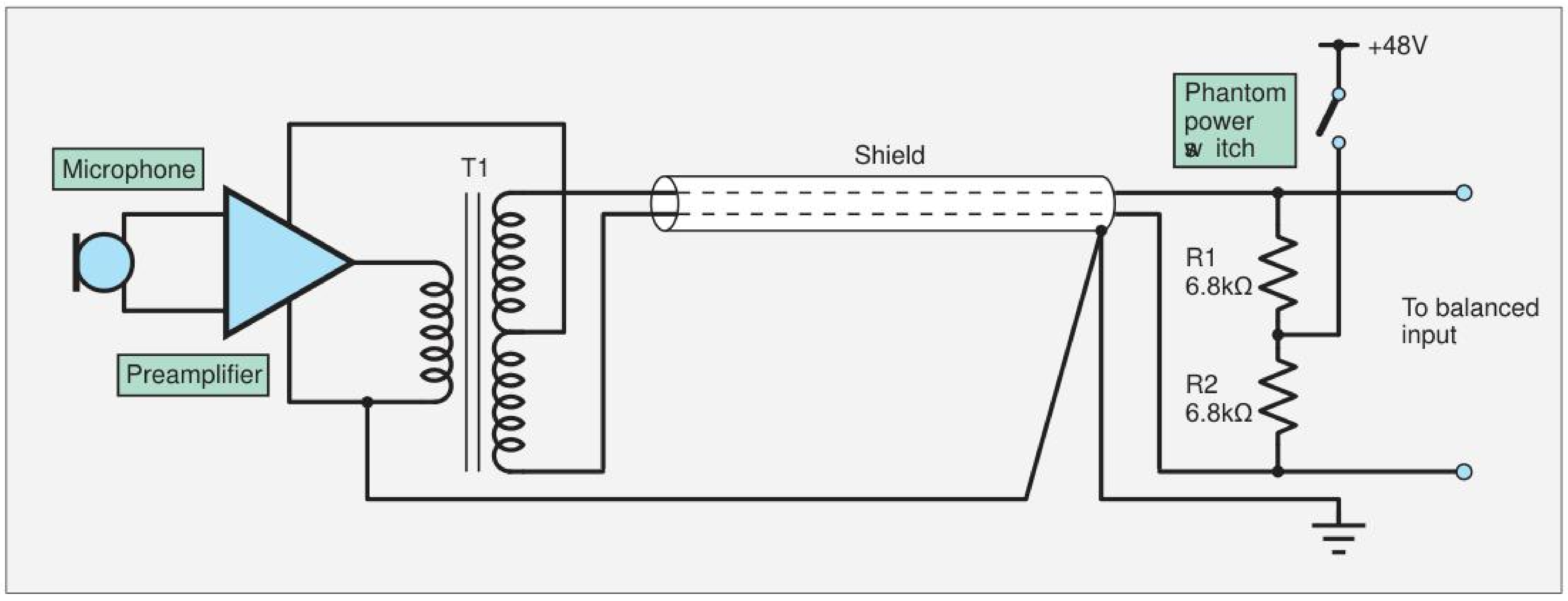


Fig.13. Phantom power circuit.

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 18

As usual, I have so many things bouncing around my poor old noggin that I don't know where to start, not the least of which is that just saying the word 'noggin' has reminded me of *Noggin the Nog* (**https://bit.ly/3ckKqed**), which was a cult classic from the golden age of British children's television when I was a kid in the early 1960s.

Revisiting Victorians

Let's start by reminding ourselves that in my previous column (*PE*, July 2021) I introduced my new hobby project, which involves recreating 21-segment Victorian displays using modern tricolour LEDs. To be honest, my chum Steve Manley in the UK is doing most of the heavy lifting on this project – designing the circuit boards, for example – with me bobbing up and down like a deranged meerkat (**https://youtu.be/57jEMZ87ND8**) in the background, offering helpful (some may say useless) suggestions.

Steve started by creating a single-character display board 50mm wide by 64mm tall. Seven of the segments have only one tricolour LED, while the other fourteen segments each have two LEDs, resulting in 35 LEDs in all. Steve also created a 3D printed 'shell' that's 10mm deep and which separates the LED board from a diffuser.

Steve and I are both creating 10-character displays, which therefore employ 10 LED boards and 10 shells. Actually, this would be a perfect time for you to take a look at a video Steve posted on YouTube that shows all of this in fantastic detail: **https://bit.ly/2T4sgXl**

Take control

Another thing we discussed in my last column is the fact that, in previous projects, Steve and I have gone our own way with regard to hardware (eg, microcontrollers) and software (eg, libraries), which resulted in an inability to share our code. In order to address this problem, in the case of our Victorian displays, we decided to employ a common platform, thereby allowing us to work on the code in a collaborative manner.

The first piece of this platform was the control board. Since we intend this board to be of use for future projects, we've added everything we can think of in a general-purpose sort of way. Our board includes a real-time clock (RTC), an audio codec with an on-board microphone so we can respond to sound, a light-dependent resistor (LDR) so we can respond to ambient light, and infrared (IR) control. It can be 'powered' by either a Teensy 3.2 or a Teensy 3.6 microcontroller from PJRC: **https://bit.ly/3h5tifW**

Lucious libraries

Remember that each of our 21-segment characters boasts 35 tricolour LEDs. These are WS2812 devices, which are known as 'NeoPixels' by the Adafruit community. One option open to us is to use the Adafruit NeoPixel library (**https://bit.ly/2T3s2zH**) to control our LEDs. Personally, I love this library, but that's probably because it's the one I first used deep in the mists of time.

The problem is that we have 35 × 10 = 350 LEDs, each requiring 24 bits of data (8-bits each for the red, green and blue channels). The Adafruit Library uses a clock rate of 800kHz, which means it takes (350 × 24) / 800,000 = 0.0105 seconds (s), or 10.5 milliseconds (ms) to upload all the data. Let's round this up to 11ms.

One point to note here is that while the Adafruit library is uploading the data to the LEDs, it's consuming 100% of the microcontroller's central processing unit (CPU) resources, which means the CPU cannot be doing anything else during this time.

I'm reasonably confident that we are going to be performing a humongous number of calculations to implement the special effects we have in mind. If we assume that we can perform all of these calculations in 9ms, this means we have a total cycle time of 11 + 9 = 20ms. In turn, this means we have a maximum refresh rate of 1,000 / 20 = 50Hz for our display. To be honest, this is probably more than adequate for this particular application but – given a choice – we'd prefer to do better.

Since we are using a Teensy 3.2 or 3.6 microcontroller, another alternative is to use PJRC's OctoWS2811 library (**https://bit.ly/3z589ZO**). This library has a limited set of in-built functions, which means you have to do things like fading from one colour to another yourself (this is true of the Adafruit library also). However, its main claim to fame is that it

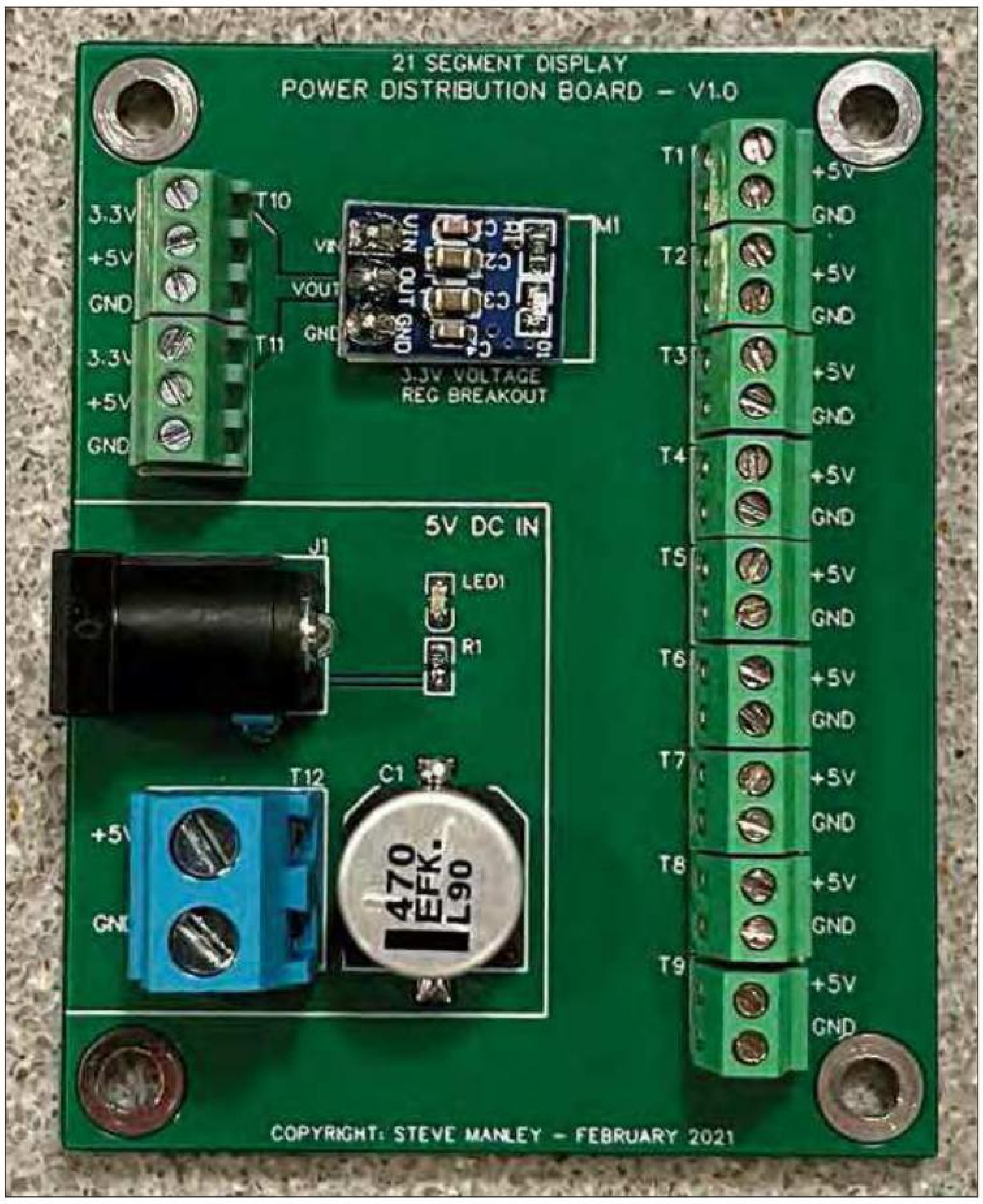


Fig.1. Power distribution board (Image source: Steve Manley).

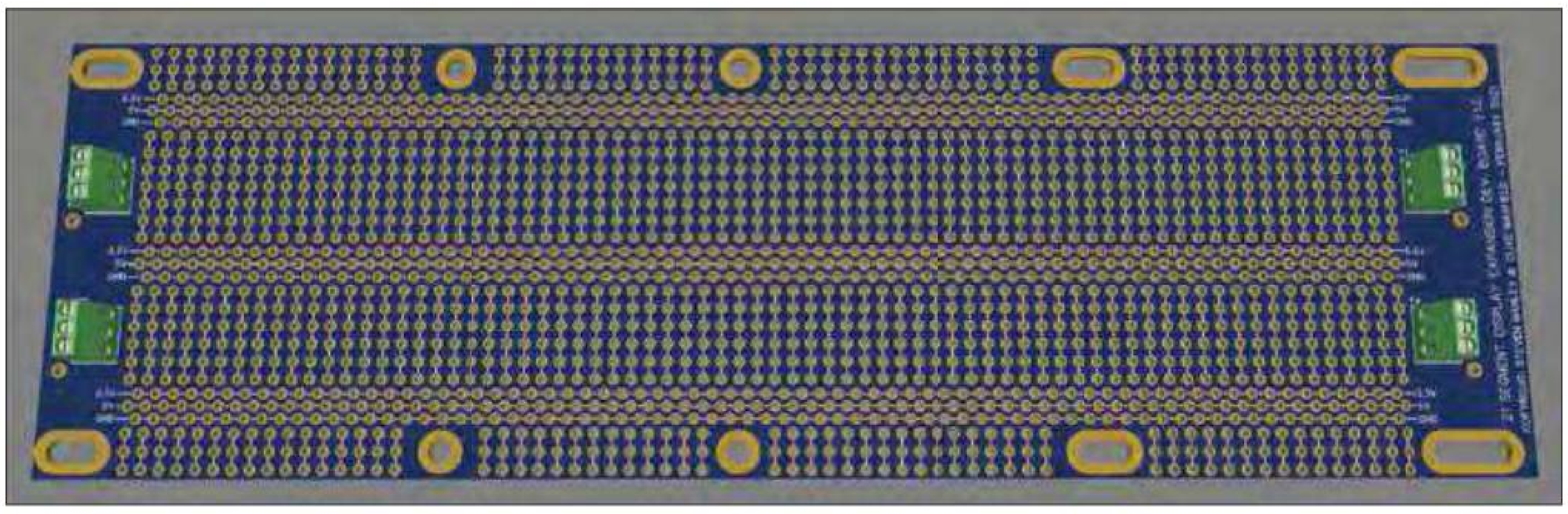


Fig.2. Prototyping board (Image source: Steve Manley)..

uses the microcontroller's on-chip direct memory access (DMA) engine to upload eight strands of LEDs simultaneously. Even better, the DMA engine runs in the background, thereby leaving the main CPU free to work on the next set of calculations. There's even a `busy()` function you can call to determine if the previous upload has finished before starting a new one.

But wait, there's more, because there's also the FastLED library (**fastled.io**), which is the one Steve favours. In addition to being targeted at lower-performance (8-bit) microcontrollers, the FastLED library offers all sorts of tasty functions, including HSV support in addition to RGB, where HSV stands for 'hue, saturation, and value' (another name for 'value' is 'brightness'). There are some awesome FastLED videos available that explain all of this in detail – just bounce over to YouTube and perform a search on 'FastLED Basics.'

The really cool thing is that the FastLED library can be used in conjunction with the OctoWS2811 library. Unfortunately, we haven't yet worked out how to set the DMA engine running in the background when using this library combo; however, we can still upload multiple strings of LEDs simultaneously. Since our Victorian displays have 10 characters, we are treating them as five 2-character pairs, and since each pair comprises 70 LEDs, this means our upload time is now reduced to (70 × 24) / 800,000 = 2.1ms, which increases our maximum possible refresh rate accordingly.

Feel the power

In the case of future projects employing fewer LEDs, we could decide to power those LEDs directly from the main control board. However, as we previously noted, each of our Victorian characters has 35 LEDs. These devices are of the WS2812B flavour that consume a maximum of 15mA for each RGB sub-channel, which means a total of 3 × 15 = 45mA per device. In turn, this means that if every LED in every segment was full-on white, each character would be consuming 45 × 35 = 1575mA, or around 1.6A, which equates to 16A for the full display. Eeek!

Obviously, this is a worst-case scenario, but it has to be taken into account. Thus, in addition to the main control board, we also decided to create a power distribution board (Fig.1). Since we were creating this board anyway, we decided to throw on a meaty 3.3V regulator, which can be used to power things like sensors in future projects.

Precocious prototypes

Although we attempted to make our main control board as all-embracing as possible, your humble narrator is oftentimes a victim of scope creep because I keep on wanting to add more and more features.

For example, in an earlier column (*PE*, January 2021), I talked about adding one of Adafruit's BNO055-based 9-DOF (nine degrees of freedom) Fusion sensor breakout boards (BOBs) (**https://bit.ly/3dP8EwU**) to my 12×12 ping-pong ball array, thereby allowing me to control the 'rolling' of a lit pixel by detecting the tilt of the array. Well, in the case of my 10-character Victorian display, I was thinking if might be fun to add a similar capability such that tilting the display to the left could cause text to 'slide' in from the right, and vice versa.

Thus, we also decided to create a prototyping board (Fig.2). There are several interesting things to note about this board. Let's start with the low-hanging fruit in the form of the mounting holes, some of which are slots. A similar arrangement is seen on the main control board (*PE*, July 2021). This came about because Steve decided to increase the gap between adjacent characters by about 3mm, which caused him to print new 3D shells that were 1.5mm wider on each side. Thus, having these slots means that our control and prototyping boards can accommodate both types of shells.

Now observe that, as opposed to having only 5V and 0V rails running horizontally across the top and bottom of the board, as would be seen on a traditional prototyping board, this board also provides 3.3V rails. Furthermore, by offsetting the vias (plated-through holes), Steve managed to

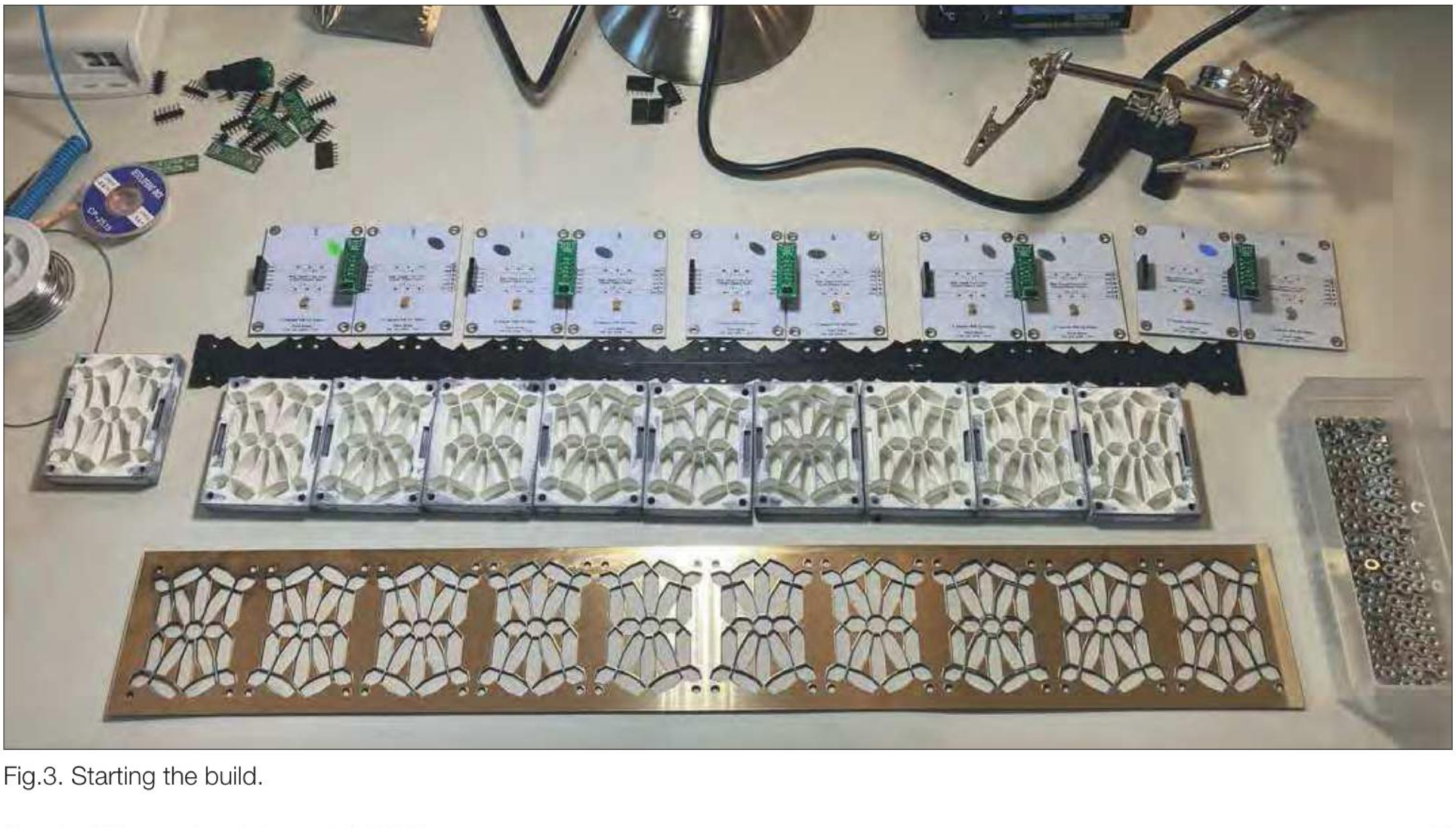


Fig.3. Starting the build.

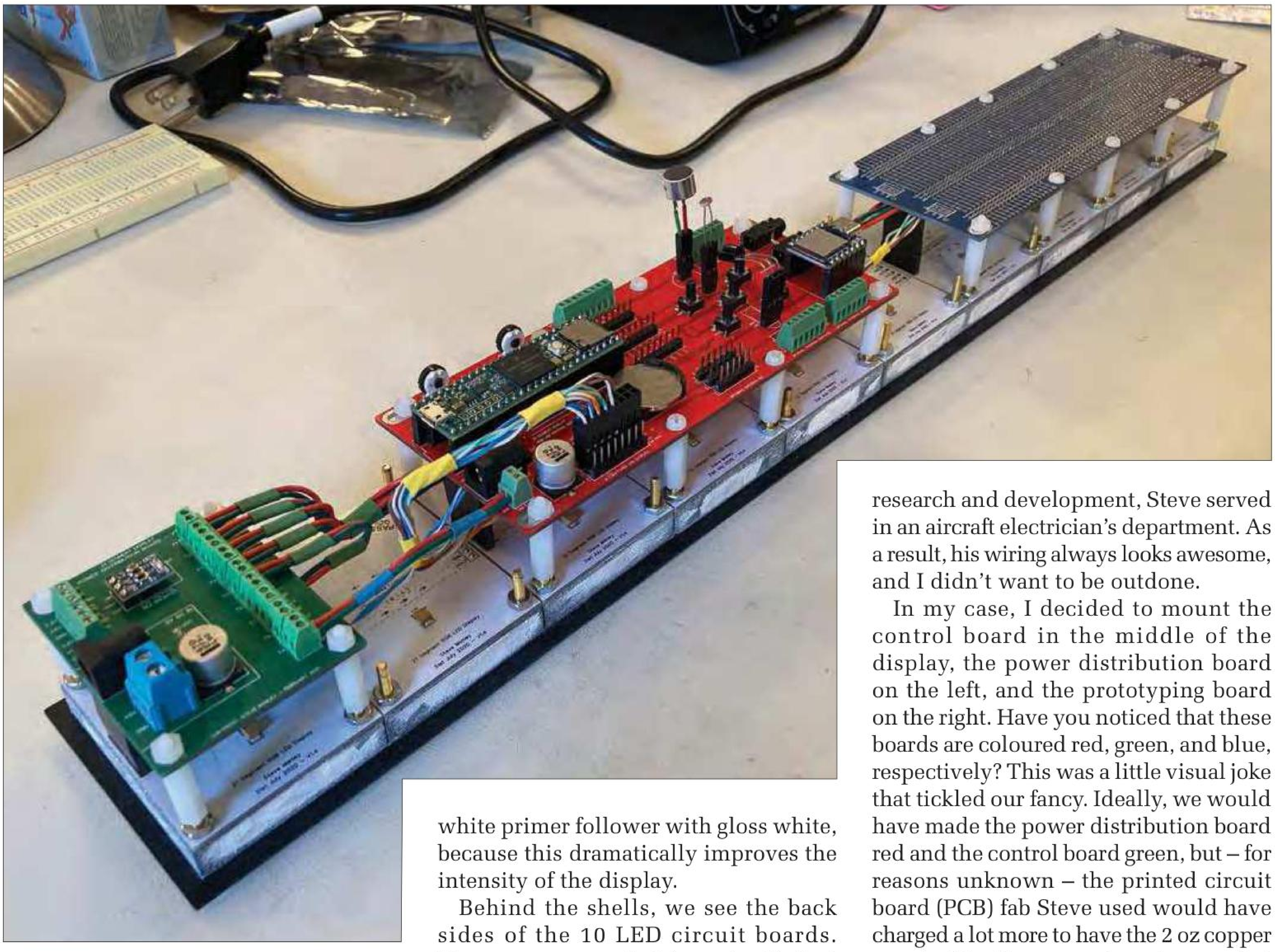


Fig.4. Feast your orbs on my wiring.

squeeze a trio of 5V, 3.3V, and 0V rails running across the centre of the board while still maintaining the traditional 0.3-inch separation between the vertical component signals on the upper and lower halves of the board. In fact, there are a bunch more innovative features associated with this bodacious beauty, but we have other fish to fry, as it were.

All together now

Before we go any further, let's take a brief stroll through the assembly of the main section of my 10-character display, commencing with all of the bits and pieces being gathered together (Fig.3).

In the middle of this image, we see the 10 shells. These were 3D printed in grey plastic. I then sprayed them with a white primer follower with gloss white, because this dramatically improves the intensity of the display.

Behind the shells, we see the back sides of the 10 LED circuit boards. These are presented in pairs linked by small bridging boards that Steve created, but that he can no longer use since he increased the spacing of his characters (Ha!).

In the foreground, we see a pseudo brass panel, which was cut for me by my chum Kevin, who is the owner of The Laser Hut in the UK (**https://bit.ly/2RqQ1Zj**). I have awesome plans for a cabinet to house my display, but we will leave that for another day.

I won't bore you with a step-by-step account of this build, save to say that the wiring took me a lot longer than I'd expected because I didn't want to let the side down (Fig.4). As I told my wife (Gina the Gorgeous), I could have wired everything up a lot faster if I was prepared to sacrifice neatness. The problem is, deep in the mists of time, as part of his apprenticeship before moving on to research and development, Steve served in an aircraft electrician's department. As a result, his wiring always looks awesome, and I didn't want to be outdone.

In my case, I decided to mount the control board in the middle of the display, the power distribution board on the left, and the prototyping board on the right. Have you noticed that these boards are coloured red, green, and blue, respectively? This was a little visual joke that tickled our fancy. Ideally, we would have made the power distribution board red and the control board green, but – for reasons unknown – the printed circuit board (PCB) fab Steve used would have charged a lot more to have the 2 oz copper required by the power board presented on a red substrate, so we went with the flow. I don't know about you, but I'm really impressed with the way this all came out (Fig.5).

A bit of a character

There are multiple ways in which we intend to use our displays. One will be to display numerical information like the date and time. Another will be to display textual messages. In order to do this, we need to decide which groups of segments need to be illuminated in order to represent the various alphanumeric characters and punctuation symbols.

In fact, there's an incredibly useful character visualisation tool available on the internet (**https://bit.ly/3wYvvyn**). This is presented on two pages, which can be selected at the top. The 'Produced' page allows you to choose between 8-, 16-, 24-,

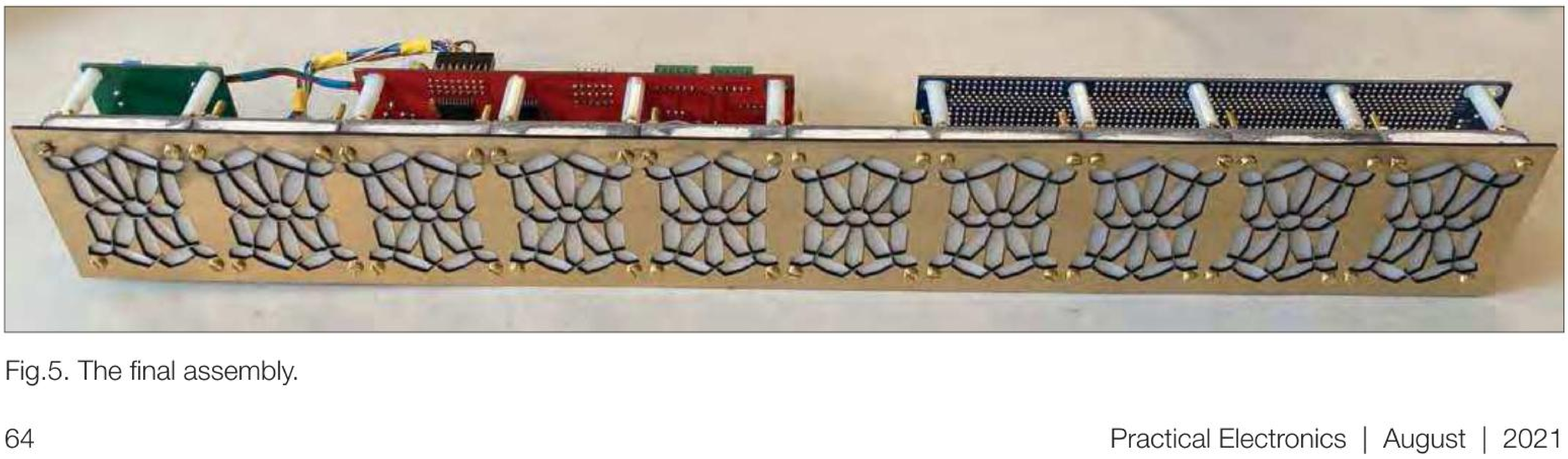


Fig.5. The final assembly.

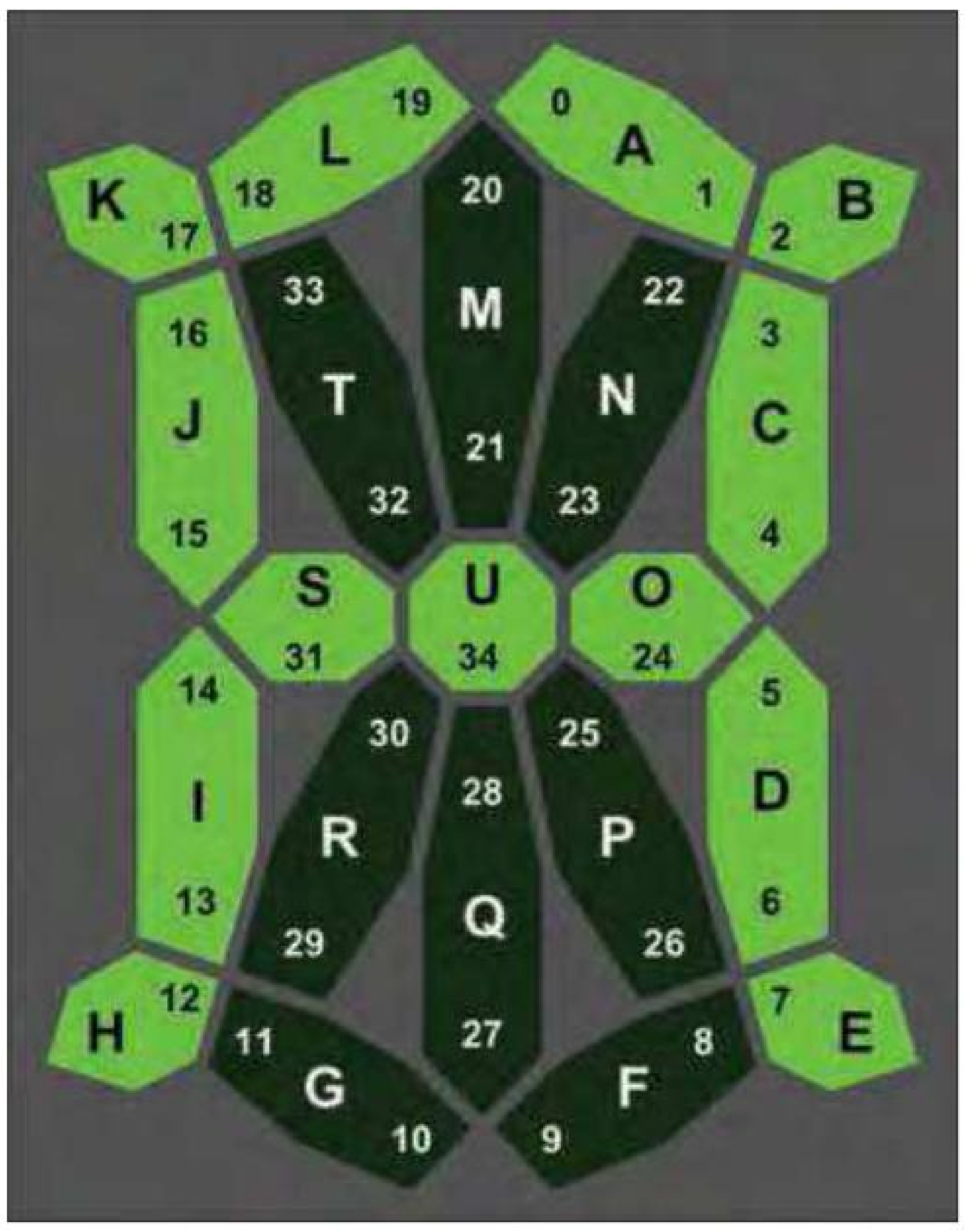


Fig.6. Segment map (Image source: Steve Manley).

34-, 43-, 66-, and 93-segment displays (the 8-segment is actually a 7-segment with a decimal point). By comparison, the 'Experimental' page allows you to choose between 6-, 21-, 23-, 50-, 52-, and 55-segment displays.

I strongly recommend that you take the time to visit and play with this tool. Go to the 'Experimental' page and select the 21-segment option. By default, the display cycles between random characters, but if you start typing you will see the characters you type appear before you. Furthermore, if you move your mouse cursor across the display, you will see whatever segment is under the cursor light up white (if that segment is currently off) or pink (if that segment is currently on). You can click on the various segments to toggle them on and off in order to see how different combinations will appear.

Come to the fore

Before we proceed, let's pause to consider our LED/segment map (Fig.6). As we see, we can think of our 21 segments as being annotated 'A' to 'U' and our LEDs as being numbered from 0 to 34. Now, we aren't going to dive deep into our code here. Suffice it to say that we have definitions of which LEDs correspond to which segments and which segments correspond to which characters. For example, our letter 'A' is defined as comprising segments A, B, C, D, E, H, I, J, K, L, O, S, and U.

Our character definitions are represented as 32-bit hexadecimal values, of which only 21 bits are used, where each of these bits corresponds to a segment, and 0 or 1 values are used to specify if that segment should be off or on, respectively.

So, how are we going to actually display our characters? Suppose we wish to display white characters on a black background. The simplest approach would be to start by turning all of the segments off (black), and then setting the segments corresponding to a '1' in our definition on (white). Alternatively, if we desire black text on a white background, then we could start by turning all of our segments on (white), and then clearing the segments corresponding to a '1' in our definition to off (black).

A more sophisticated approach – the one we are using – is to have the concept of a foreground colour, a background colour, and a mask. Let's say that we set our background colour to black and our foreground colour to white. Our character definition acts as the mask. In the case of the segments corresponding to a 0 in our character definition, we display the background colour. By comparison, in the case of the segments corresponding to a 1 in our character definition, we display the foreground colour.

Thus far, we've assumed static colours. Where this starts to get really clever is if we allow both our background and foreground colours to be dynamic. For example, we could present a constantly changing rainbow of colours on the segments forming our background while having the foreground colour a static white. Furthermore, each of the background segments could be the same rainbow colour, or we could have the rainbow rippling across the display.

Slicing and dicing

Once you've wrapped your brain around the foreground-background concept – in particular, the fact that any of the effects we are displaying are logically separated from the way in which we control the segments to represent the characters – then you will start to realise just how powerful this technique can be.

This leads us to consider different ways in which we might decide to 'slice and dice' our LEDs. For example, we could think of them as being concentric rings (Fig.7a). In this case we could implement what Steve and I refer to as a starburst effect with different colours radiating out from the centre. Steve created an example video showing this type of effect on two adjacent characters (**https://bit.ly/3fZTkjT**). Now imagine displaying the date, time or text with this starburst effect applied to the background colour and the foreground colour set to white. Alternatively, imagine this effect applied to the foreground colour with the background colour being set to black.

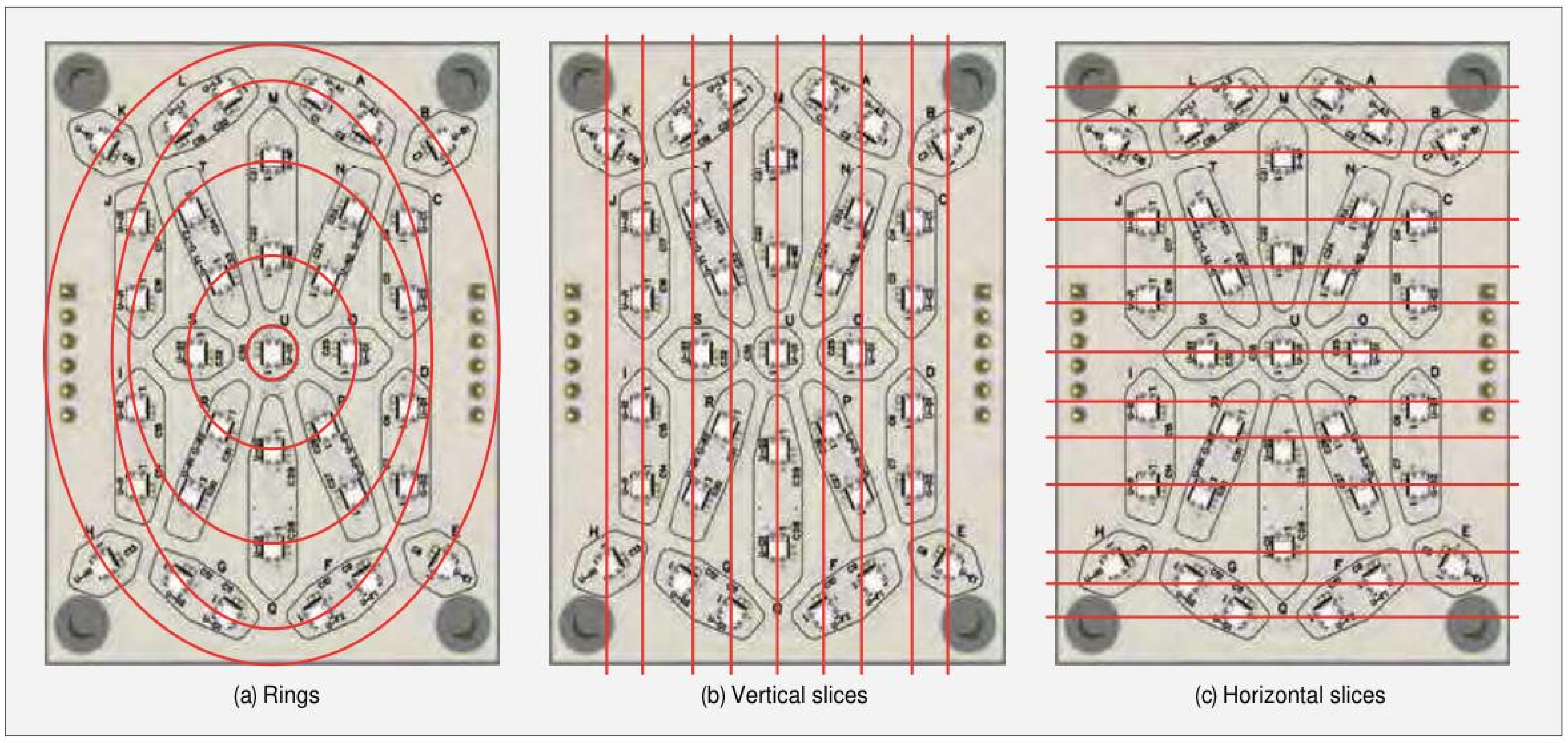
Similarly, for some effects we might want to think of the LEDs being grouped in vertical 'slices' (Fig.7b), while for other effects (eg, a graphic equaliser or audio spectrum analyser) we might want to consider the LEDs as being grouped in horizontal 'slices' (Fig.7c).

Get SMAD!

It was around this point that we ran into a bit of a problem. In future columns, I would love to share code examples with you, but the code for our Victorian displays is a tad too complex to show anything meaningful in this sort of setting. Also, it's unlikely that many readers would want to invest the time and effort (and money) in building something like one of our 10-character 21-segment Victorian displays.

But turn that frown upside down into a smile because we have a cunning plan. Indeed, it's a plan so cunning that we could pin a tail on it and call it a weasel, as Blackadder would say (always remember that, while eagles may soar, weasels rarely get sucked into jet engines).

What we've done is to create a special incarnation of our original display, where this new version is called a *SMAD* (*Steve and Max's Awesome Display*). As you can see, this has the hint of a sniff of the look-and-feel of one of our Victorian displays, but it's more symmetrical


(a) Rings

(b) Vertical slices

(c) Horizontal slices

Fig.7. Different ways of slicing and dicing the LEDs.

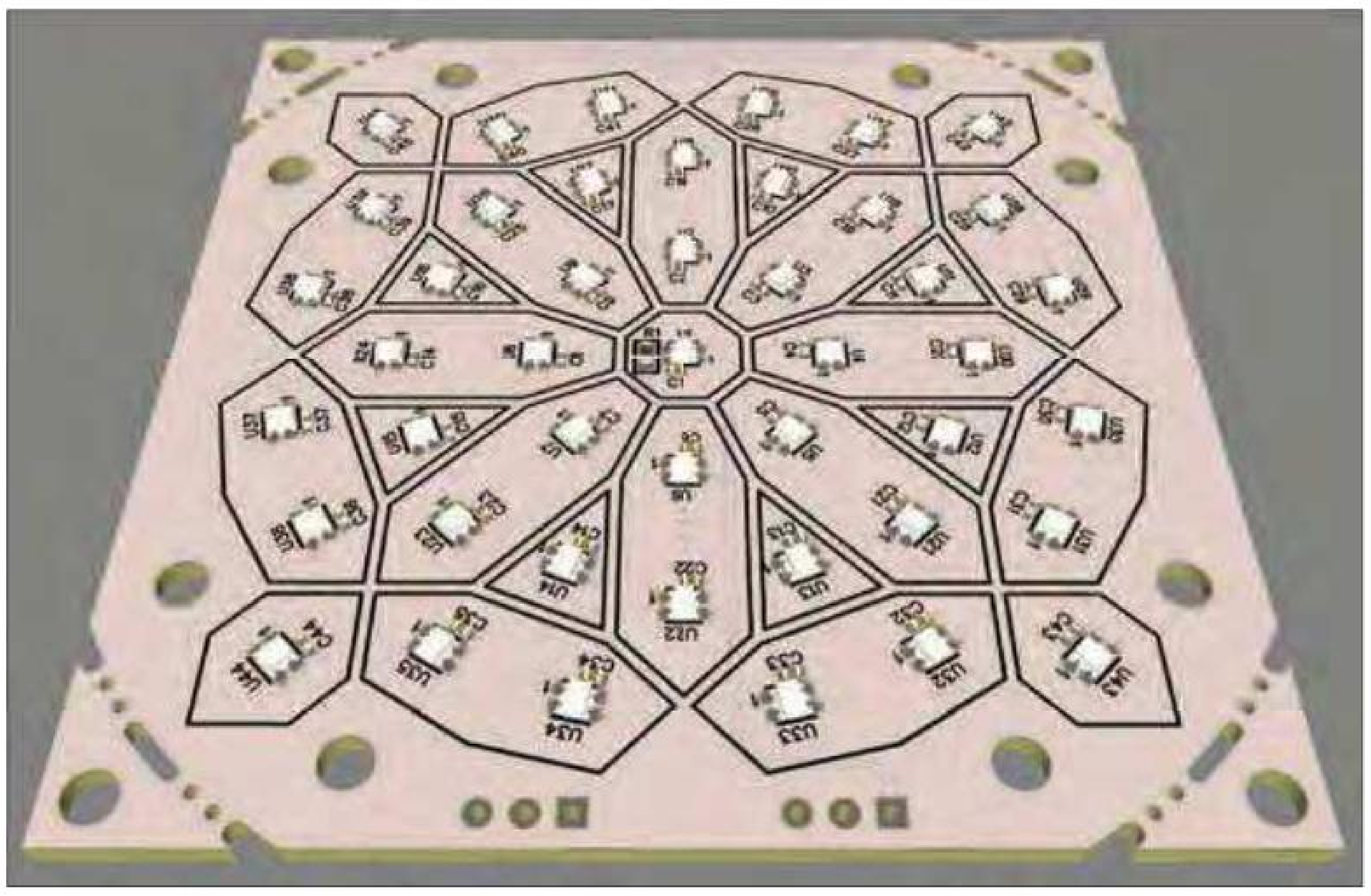


Fig.8. *SMAD* circuit board with 45 tricolour LEDs (Image source: Steve Manley).

and contains 45 tricolour LEDs grouped into 29 segments (Fig.8). In this case, the devices we are using are of the WS2812C flavour that consume a maximum of only 5mA for each RGB sub-channel, which means a total of 3 × 5 = 15mA per device. This means that if every LED in every segment was full-on white, each character would be consuming only 15 × 45 = 675mA or around 0.7A.

The really exciting news is that these *SMAD* boards, which are a modest 70mm × 70mm square, are available from the *PE PCB Service* (**https://bit.ly/3wVUgLq**) for only £11.95 each, which includes shipping in the UK (shipping outside the UK will be quoted separately). Observe that there are two sets of 0.1-inch pitch 3-pin pads shown in the foreground of this image. One set comprises 0V, 5V and Data-in (the legends are on the back of the board); the other comprises 0V, 5V and Data-Out (for use if you wish to daisy-chain multiple *SMADs* together). Note that you'll have to provide your own 3-pin headers, or you can solder wires directly to the pads.

In future columns, in addition to cogitating and ruminating on our Victorian displays, we will be perusing and pondering small test programs to run on our *SMAD* boards. I'm thinking that, as one of our experiments, we could make it react to sound in interesting ways. As a tempting teaser, take a look at a video of an early test that Steve performed as soon as the boards arrived back from fabrication and assembly (**https://bit.ly/3z5xCSJ**). On the left we see a bare *SMAD* board; on the right we see a *SMAD* with a 29-segment 3D printed shell and diffuser (Fig.9).

For our diffusers, we are employing the white plastic separator sheets you can purchase to use with file folders, such as the white polypropylene dividers from Toner Ink Online (**https://bit.ly/3inEODY**). If you look closely, in the right-hand image, you can see the corners of the square circuit board sticking out from behind the round shell. This explains the 'breakaway' holes and slots in the corners of the board in Fig.8. If you break these corners off, the contour of the board will match the contour of the shell.

As you will discover, we can create mind-boggling 'Ooh!' and 'Aah!' effects using a single *SMAD*. Now, imagine what we can do with two. Do you remember the WALL-E animated movie in which the friendly little robot had two big eyes? Well, that's what I'm planning on doing – creating a simple 'head' that has two *SMADs* as eyes and then seeing what effects I can create, like 'blinking' or 'looking' left, right, up and down. Maybe using colours to reflect emotions like happy, sad and angry. The world is our lobster (or oyster or crustacean of our choice).

29 or 45?

I must admit that I was a happy chappy – a man with a plan (if we don't have a plan, we're no better than arts students, as the saying goes) – until that little scamp Steve threw a great big spanner into the works. The man simply cannot stop playing with his 3D printer. As we saw in Fig.8 and Fig.9, *SMADs* were originally conceived as being 29-segment displays with 13 small segments containing one LED each and 16 long segments containing two LEDs each. But then Steve decided to see what would happen if he created a shell that partitioned each of the longer segments into two halves, thereby creating a 45-segment display.

Originally, I was not a fan of this idea because I like the subtle gradient effects that can be achieved by mixing two colours in the same segment. But then Steve created a new video and now I'm not so sure (**https://bit.ly/3pqNavS**). On the left we see a bare *SMAD* board, in the middle we see a *SMAD* with a 29-segment 3D-printed shell and diffuser, and on the right, we see a *SMAD* with a 45-segment 3D-printed shell and diffuser (Fig.10).

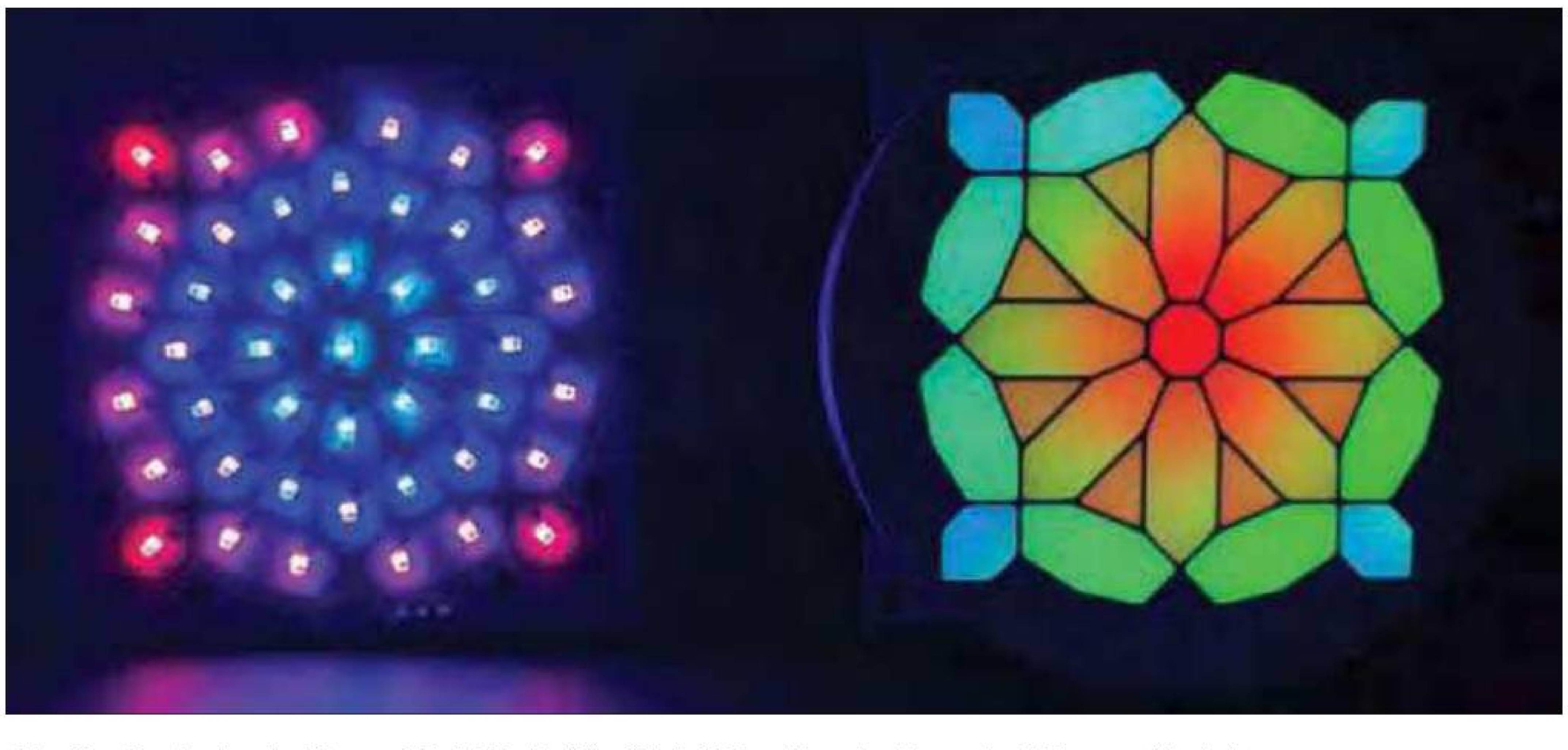


Fig.9. Early test: Bare *SMAD* (left). *SMAD* with shell and diffuser (right).

We now tend to refer to the 29-segment and 45-segment incarnations as a 'gradient fill' and 'stained glass' shells/*SMADs*, respectively. The problem is that I can't decide which I like best. As a result, I now have to build *two* robot heads, one boasting a pair of gradient fill eyes and the other flaunting a brace of stained-glass eyes.

For your delectation and delight, if you decide to purchase one or more *SMADs* and you wish to print your own 3D shells, then Steve has kindly made his DXF and STL files available to us. Compressed ZIP files containing these design files are available on the August 2021 page of the *PE* website at: **https://bit.ly/3oouhbl** – files **CB-August21-01.zip** and **CB-August21-02.zip** contain the files for the 29-segment and 45-segment displays, respectively. If you do determine to avail yourself of these files, you'll see that the shells come in three pieces: back, front and facia (or faceplate). Steve split the main 10mm-thick shell into the two 5mm-thick front and back sub-shells in order to make them easier to spray-paint. The thin sheet of white plastic diffuser is placed between the front shell and the 1mm-thick facia.

But wait, there's more... Do you recall earlier in this column when I mentioned my chum Kevin, who is the owner of The Laser Hut? Well, on the off chance you don't have a 3D printer, but you still want some shells for your *SMAD* displays, Kevin can use his lasers to cut shells out of 9mm-thick MDF, along with facias cut out of 1mm-thick black or pseudo-metallic (nickel) materials. In fact, Kevin sent me a video of the laser cutting a pseudo-nickel facia (**https://bit.ly/3cn7ucu**).

As I pen these words, I have four MDF shells winging their way to me – two

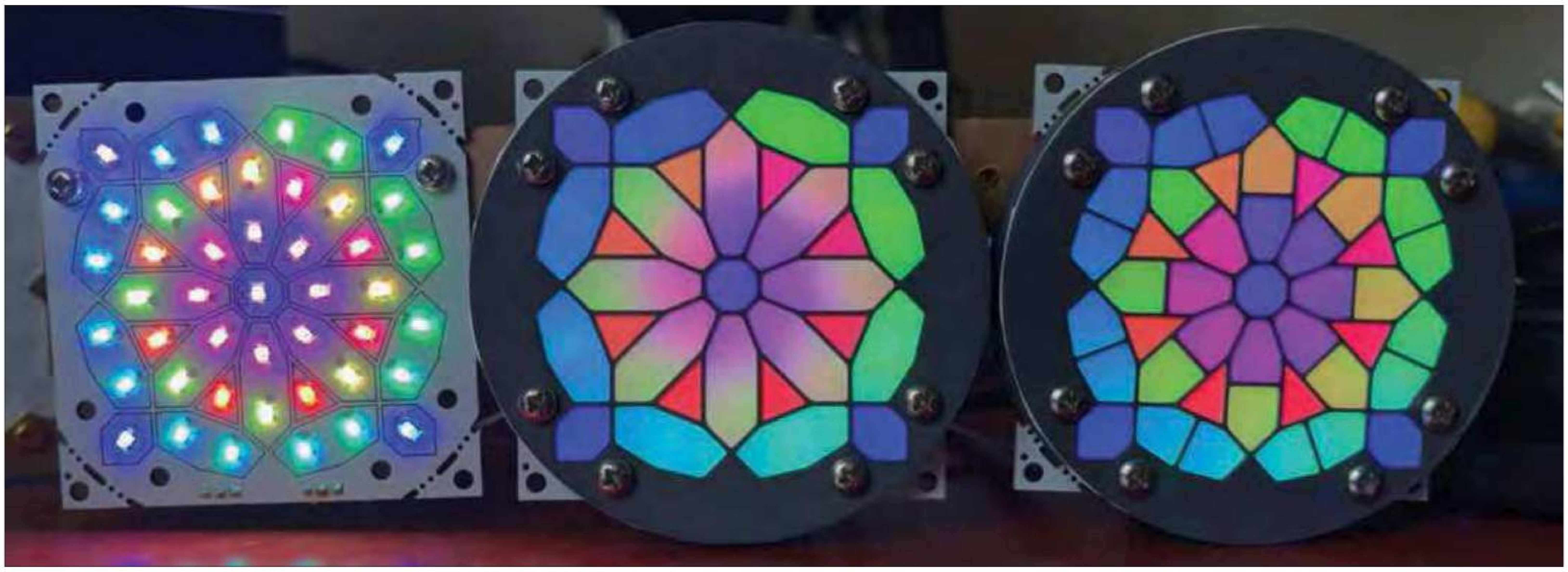


Fig.10. Bare *SMAD* (left), 29-segment shell (middle), and 45-segment shell (right).

29-segment and two 45-segment. Each of these shells is accompanied by two faceplates, one black and one pseudo-nickel. I shall report further in a future column. For the moment, let me just say that Kevin has agreed to supply these little rascals to anyone who wants them (you can contact him at **pe@thelaserhut.co.uk**). One 9mm-thick MDF shell and one 1mm-thick face plate (your choice of black or pseudo-nickel) will cost £10, while two of each will cost £18. In both cases, the postage will be £1.60 in the UK (postage outside the UK will be quoted separately).

Next time

Eeek Alors! This column has certainly 'grown in the telling.' I'm scared to think what our illustrious editor and publisher Matt Pulzer is going to say when he sees how big it is. I only hope that the radiance of Matt's smile will continue to lighten my life. In my next column, we will delve deeper into matters pertaining to my 10-character 21-segment Victorian display, and we will also start to create some experimental code and effects to run on our *SMAD* displays. Until that frabjous day (Callooh! Callay!), as always, I welcome your sage comments, insightful questions and helpful suggestions.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

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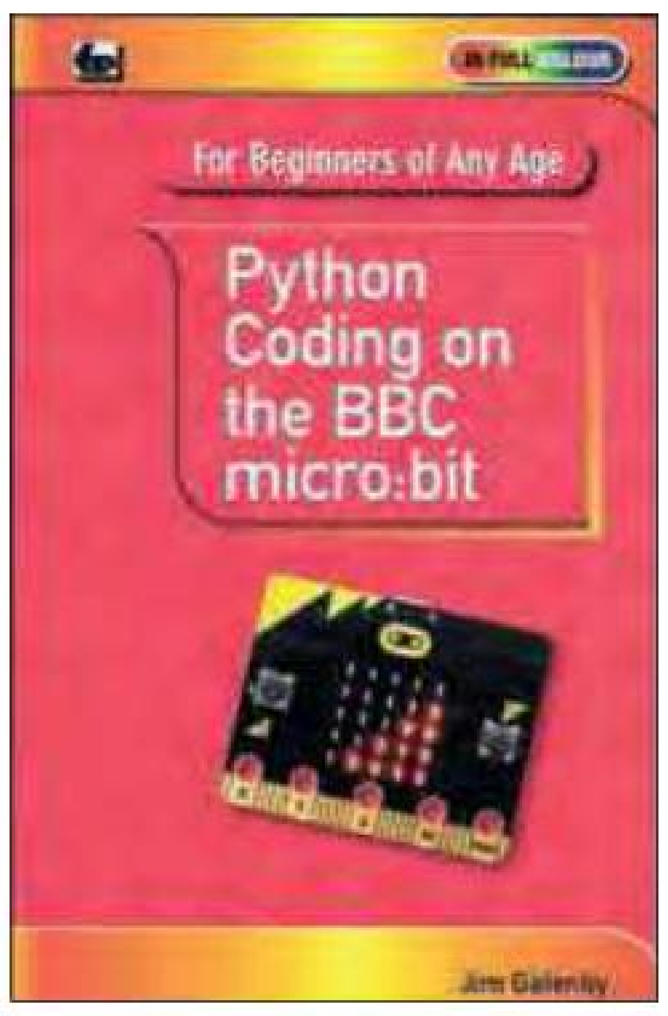


PYTHON CODING ON THE BBC MICRO:BIT

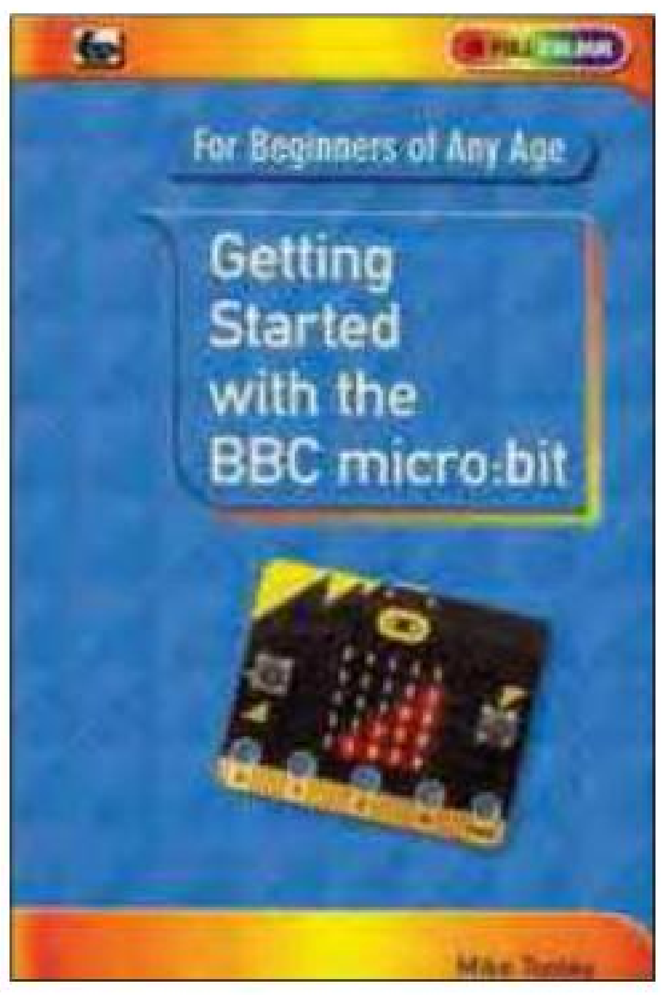
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

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Next Month – in the September issue

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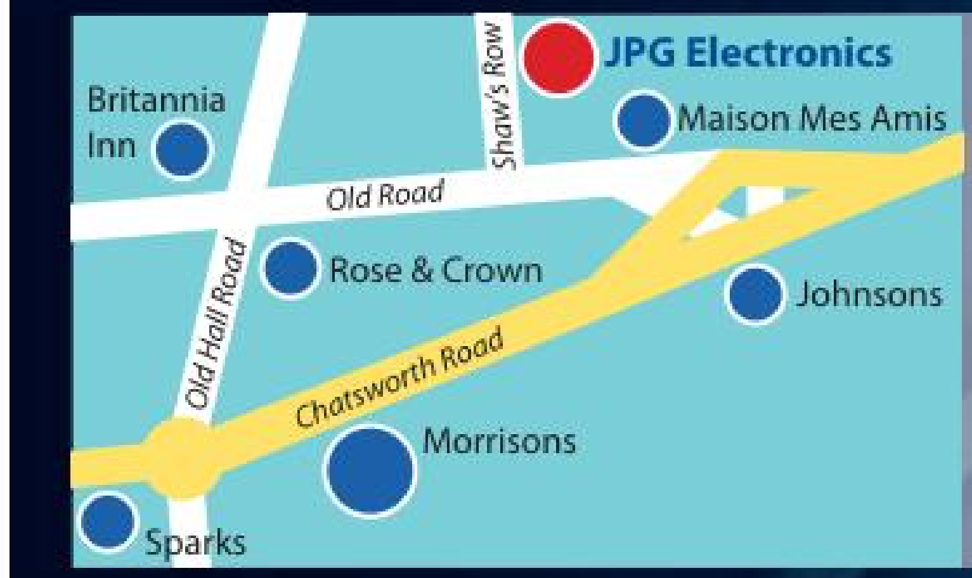

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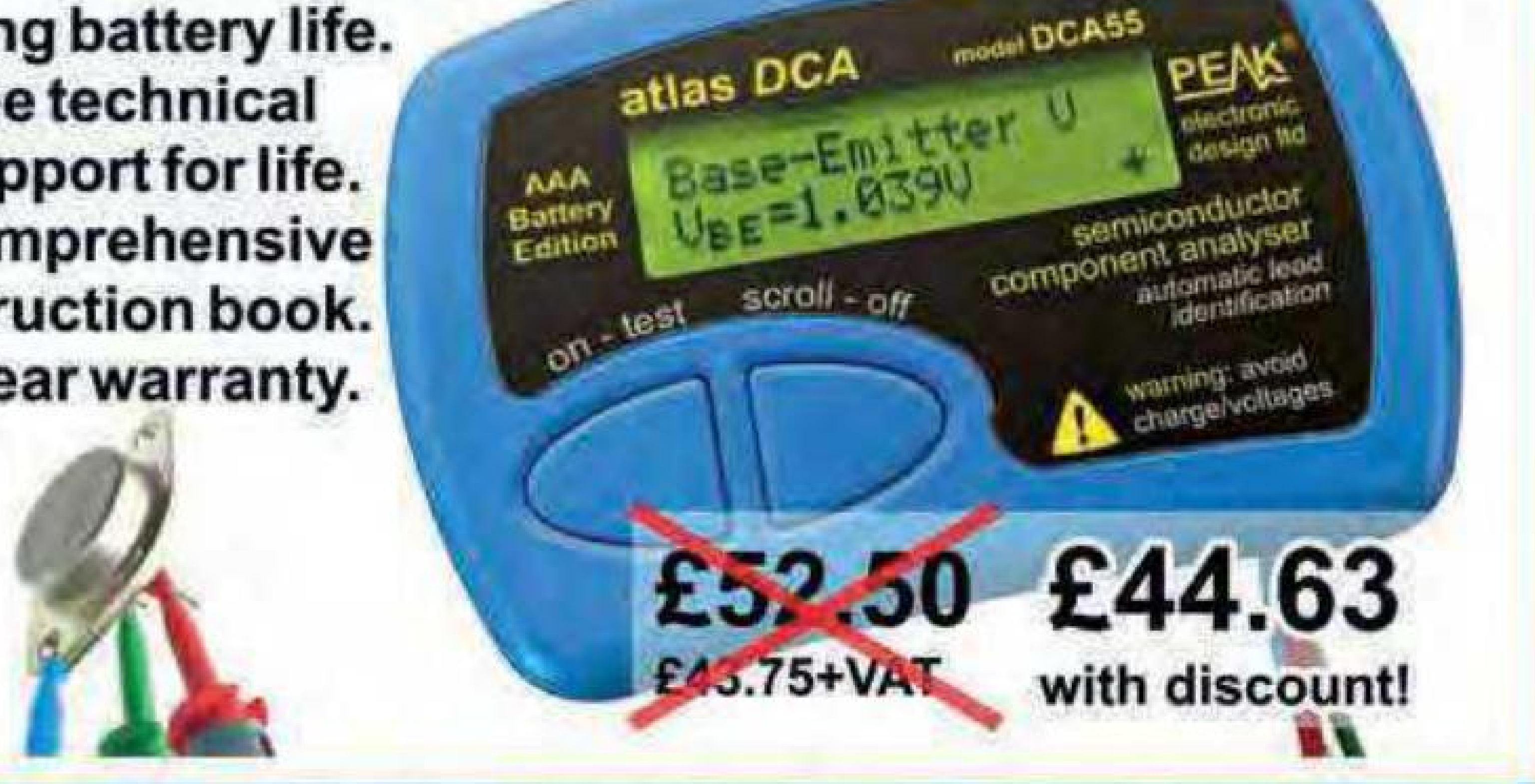

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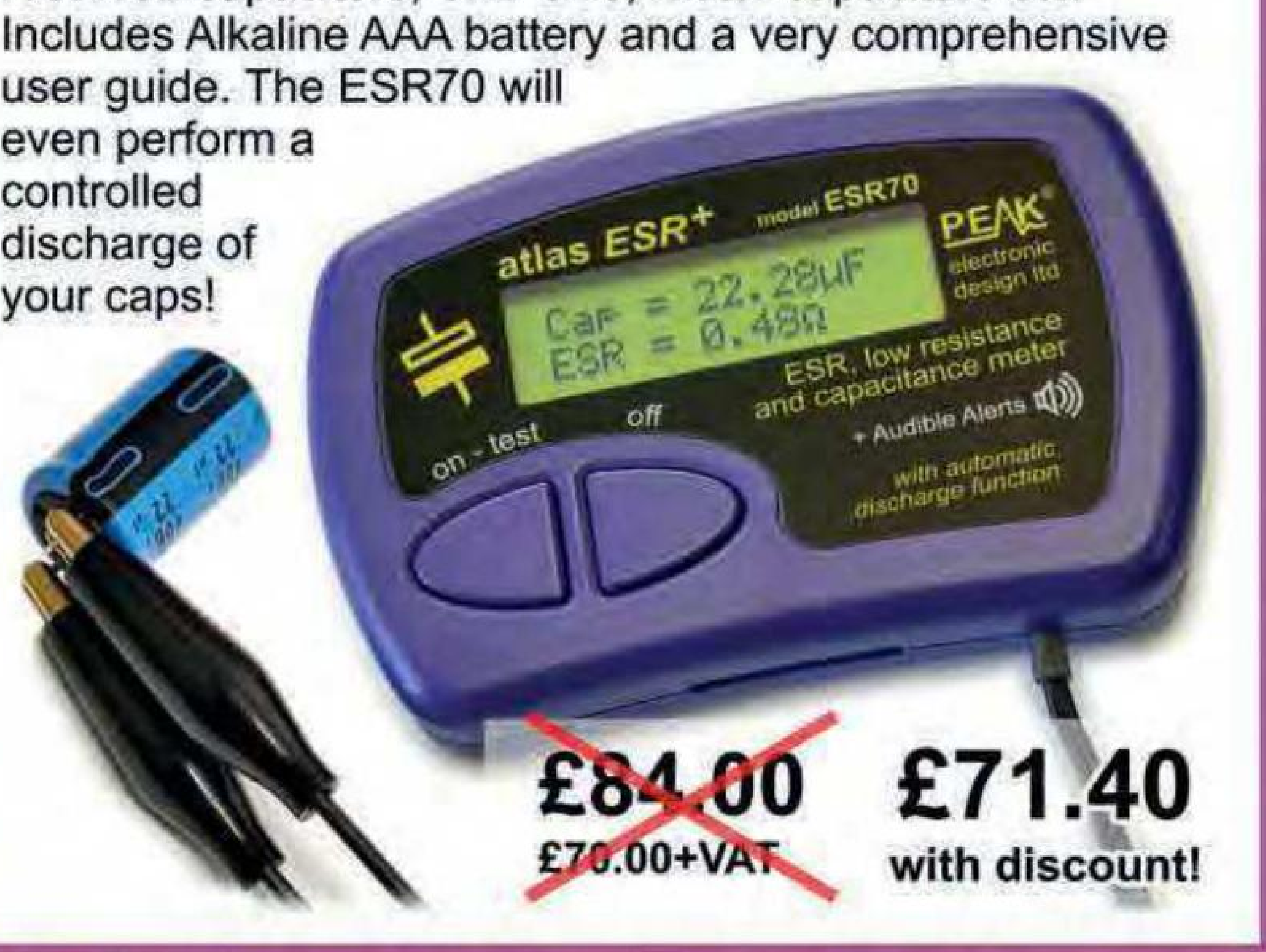

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